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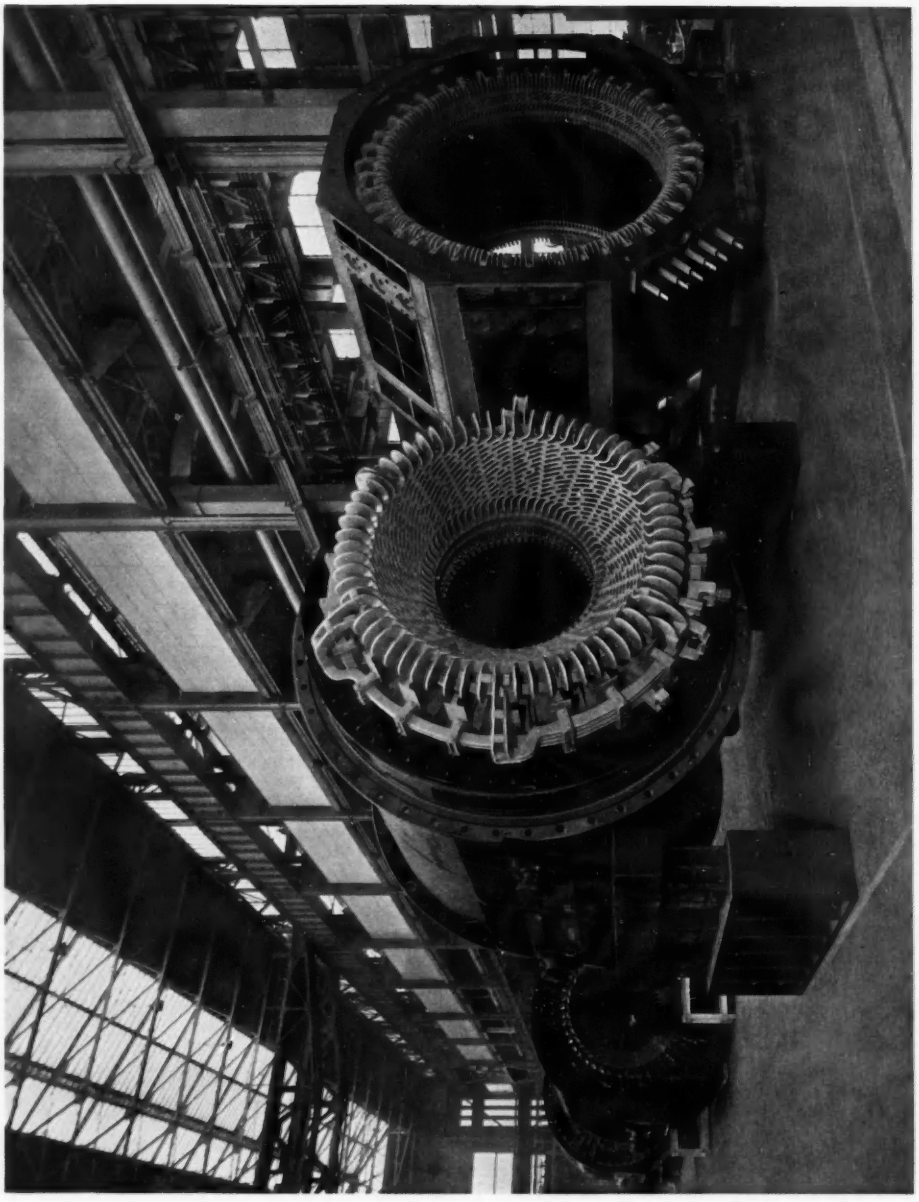

TURBO-ALTERNATORS UNDER CONSTRUCTION AT WITTON ENGINEERING WORKS.

An A.C. Winder Installation in the Orange Free State Goldfields, South Africa

By C. W. MYRING, Chief Electrical Engineer and C. MEYER, Chief Mechanical Engineer
The British General Electric Co. Ltd., Johannesburg.

INTRODUCTION.

PIONEERING work, which led to the discovery of gold and the subsequent development of the Orange Free State Goldfields, dates back to October, 1933, when geophysical prospecting and borehole drilling began. This work was carried on by several companies with varying success until 1939 when the outbreak of the second World War brought a temporary halt to activities. However, by that time borehole drilling had disclosed payable values, and sufficient information had been gained to indicate the gold-producing potentialities of the area.

On the cessation of hostilities, work began again, and twenty-six large shafts were started within a period of less than four years, the greatest shaft-sinking campaign ever undertaken in mining history. Thirteen mines are now in the course of development, of which two have recently reached the production stage, a typical reduction plant being shown in fig. 1. A conservative estimate of the average life of these new mines is 40 years.

Power for this enormous development is being supplied at present through a transmission network from the Electricity Supply Commission power stations in the Vereeniging area 115 miles away, but ultimately a large new power station, which is under construction at Vierfontein about 55 miles north of Welkom, will supply the whole area.

The Free State Goldfields form a solid block about 30 miles in length, and up to 8½ miles wide, with the new town of Welkom, some 165 miles from Johannesburg and 90 miles from Bloemfontein, situated in the centre. The new mines cover an area of well over 160 sq. miles

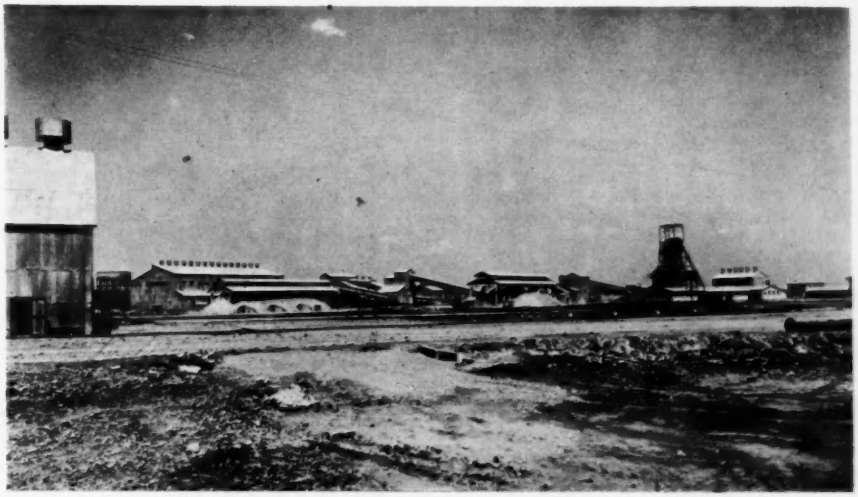

Fig. 1.—A typical reduction plant at one of the mines in the Orange Free State.

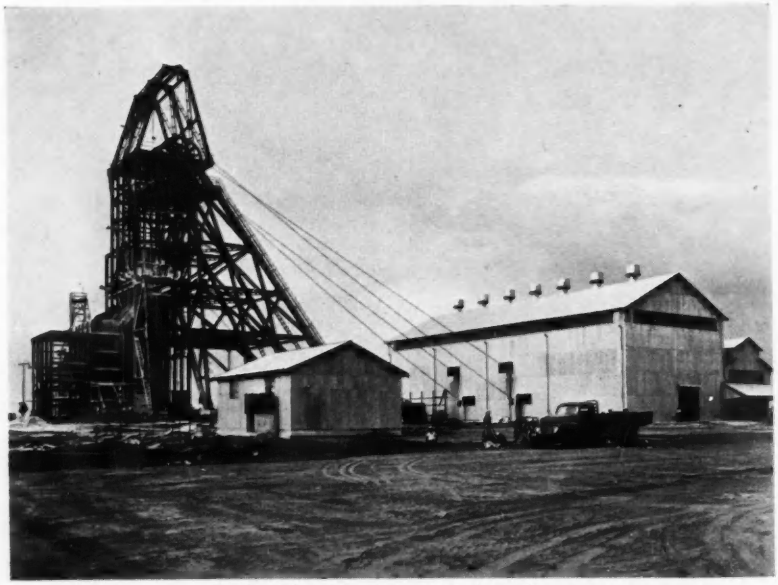

Fig. 2.—The pithead gear and winder house.

and when these goldfields are fully developed this figure is likely to reach 250 sq. miles.

The country is flat and, with the exception of a few isolated farm houses, was bare veldt before mining operations began. The climate is dry and healthy, the elevation being about 4,500 ft. above sea level. Day temperatures of nearly 100 degs. F. are experienced during the summer months but, due to the altitude, the nights are reasonably cool. Extensive tree planting is being undertaken, and in time will greatly improve the somewhat barren landscape.

Odendaalsrus, original centre of operation, is now but one of four towns resulting from mining development, the others being Virginia, Allanridge and Welkom. Immediately adjacent to Odendaalsrus is the new mine to which this article refers, where four 4,200 h.p. double drum, A.C. electric winders have been

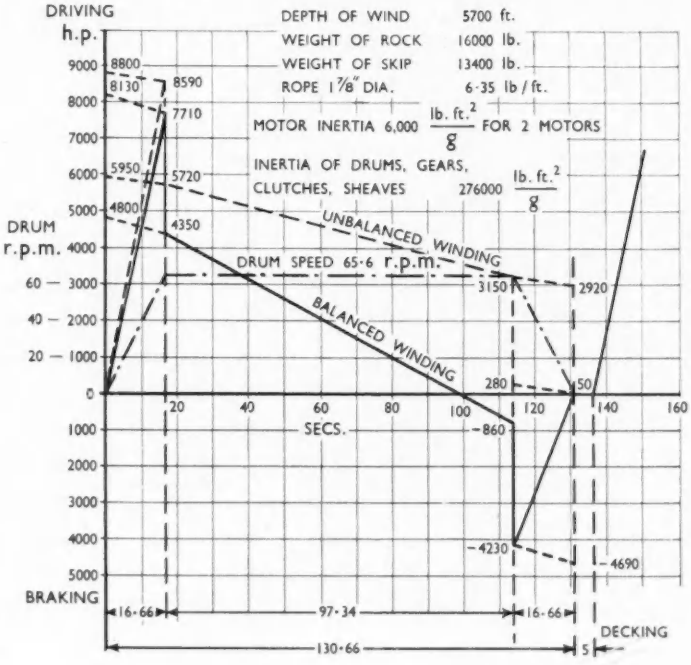

Fig. 3.—Diagram of hoisting duty when winding rock.

installed and commissioned by The General Electric Co. Ltd.

The installation is of particular interest since these are the first winders to use the Company's new dynamic braking and motor control system. The plant was first brought into service for shaft sinking and operated three 8-hour shifts a day for seven days a week with only occasional short breaks for maintenance. During that time the performance of the equipment has fully justified the adoption of the new control system which has proved completely successful.

WINDERS.

At this mine are two 47 ft. by 11 ft. rectangular shafts, the proposed initial depths of which are 6,000 ft. and 5,000 ft. respectively. Each is divided into seven compartments, four of which are for winding, and the others for ventilation and pipes.

The cost of sinking to such depths is very heavy, so that it is essential that each shaft should serve as large a claim area as ventilation and tramming conditions will allow. Ventilation is particularly important because the mines are both deep and hot with rock temperatures exceeding 100 degs. F. and the spacing of the shafts 8,000 ft. apart was largely determined by ventilation considerations.

Each shaft is served by two double drum A.C. electric winders, the winder house and pithead gear of No. 2 North shaft being shown in fig. 2. The winders, which are used for handling rock, men and material, normally work in balance, but are also capable of handling the maximum unbalanced load. Each winder will handle 16,000 lb. of rock per wind, giving a maximum output, based on 12 hours' rock hoisting a day for 25 days a month, of approximately 57,000 tons, or a monthly tonnage from the mine of 228,000 tons. The diagram of the hoisting duties when handling rock is shown in fig. 3.

The full complement of underground workers, representing 5,500 men, can be lowered down the two mine shafts within 1¼ hours in double deck cages having a capacity of at least 62 persons with a total weight of 9,300 lbs. The maximum hoisting speed is 3,000 ft. per min., with acceleration and retardation rates of 3 ft. per sec. per sec., the hoisting duty diagram being shown in fig. 4.

The mechanical parts of the winders and the layout of the equipment were designed by Fraser and Chalmers, the Company's Mechanical Engineering Works at Erith, and, except for gears and drum shafts, were made in South Africa by the East Rand Engineering Company.

The winders, one of which is shown in fig. 5, have double parallel drums 14 ft. dia. by 7 ft. wide. The drums are loose on the drum shaft and driven through multiple tooth clutches which permit close rope adjustment and also allow either drum to be used for an unbalanced load. The drums have parallel grooves which accommodate the 1⅞ in. dia. rope in four layers.

The winders are driven through double helical reduction gears manufactured by David Brown & Sons. Two pinions engage with the gear wheel; lubrication is by oil spray in an oil tight gear case.

Parallel motion suspended brakes of standard design are provided for each drum and are oper-

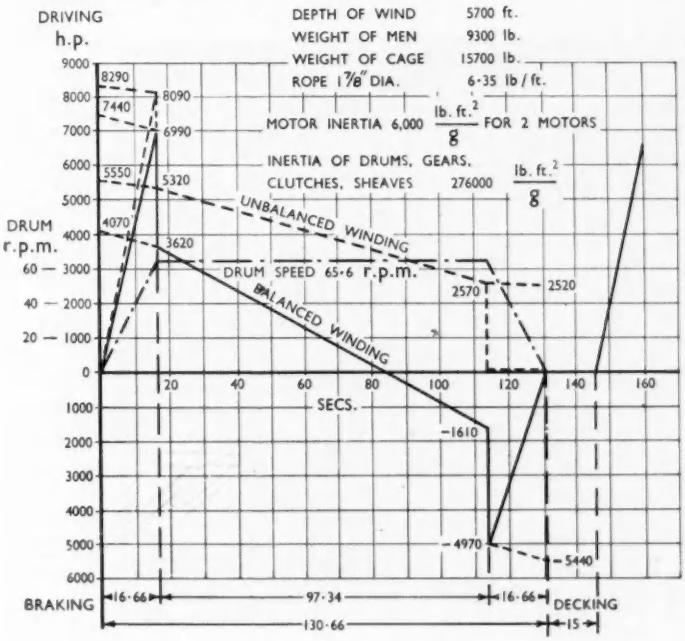

Fig. 4.—Diagram of hoisting duty when winding men.

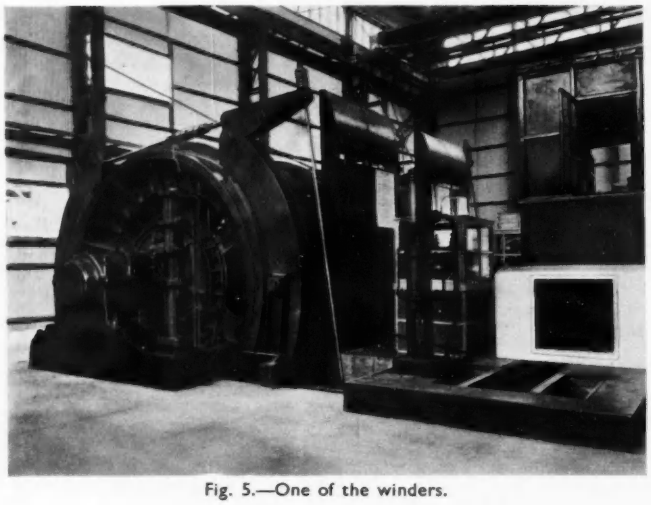

Fig. 5.—One of the winders.

ated by weight brake engines. Both brake and clutch engines are operated by the mine's air supply, but two standby compressors, having an output of 100 cubic feet of free air per min. and driven by 25 h.p. motors, are installed.

In place of the usual large depth indicators there are two miniature depth indicators mounted on the driver's desk with the electrical instruments. The depth indicators are mechanically driven from each drum. Two long range Lilly controllers, one driven from each drum, prevent overwinding or overspeed.

ELECTRICAL EQUIPMENT

The whole of the electrical equipment was designed and manufactured at the Witton Engineering Works.

MOTORS.

Each winder is driven by two 2,100 h.p., 6·6 kV, 370 r.p.m. slipring induction motors. These machines are of the protected type and it will be seen from fig. 6 that the shafts and bedplates are extended to permit the stators to be racked clear of the rotors so that inspection and maintenance can be undertaken without dismantling the machine.

Since the two motors driving the winder are coupled together through the reduction gearing, and both their stator windings and rotor windings, respectively, are connected in parallel (fig. 14), they will share the load equally only if the

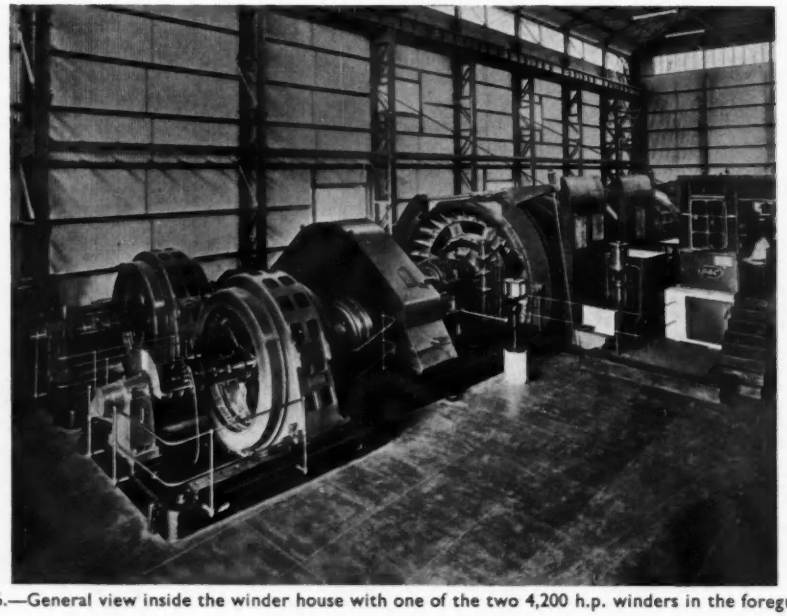

Fig. 6.—General view inside the winder house with one of the two 4,200 h.p. winders in the foreground.

voltages induced in their respective rotors are equal and in phase. The induced voltages in the rotors will be equal because they are identical machines and are coupled together. It is necessary, however, to take suitable steps to ensure that these voltages are in phase. During manufacture of the machines, the stator and rotor connections were located as accurately as possible in relation to the stator frame and coupling keyways respectively, so that the stators and rotors are as near identical as possible. During erection of the plant, advantage was taken of the large number of slots provided on the Wellman-Bibby couplings to locate the rotors accurately in the correct phase position. The fact that the number of slots on the Wellman-Bibby couplings was not an exact multiple of the number of poles of the machines, provided, in effect, a vernier adjustment. This combined with the possibilities of reversing the three phases of the stator or interchanging a phase of the rotor of one machine, enabled a very close setting of the phase positions to be obtained.

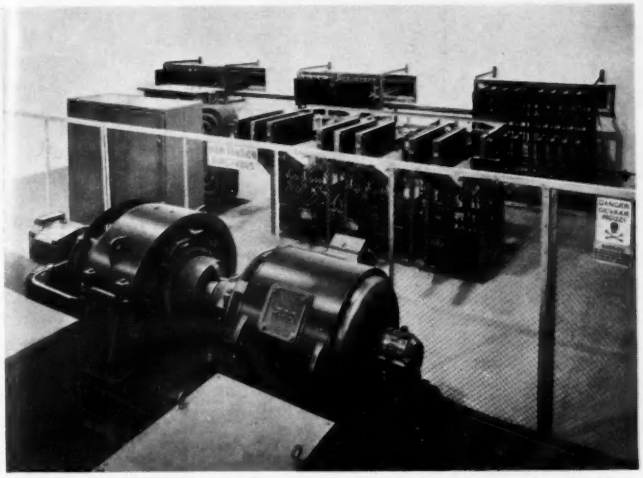

Fig. 7.—Part of the control equipment showing the dynamic braking motor generator in the foreground, the stator reversing and dynamic braking contactors, and rotor contactors.

The procedure adopted was as follows:

The rotors were disconnected from the rotor resistances; one machine only was coupled to the reduction gears and the coupling springs were removed from the coupling of the second rotor. The stators were excited at low voltage and the rotor of the second machine was turned until a position was reached where the voltages induced in the two rotors were in phase and slots of the coupling for the second machine were in alignment. The springs were then reinserted in the coupling of the second rotor.

Control Gear.

Much of the control gear is standard equipment so that only a brief reference is made to principal items. The incoming 6·6 kV supply to the winders is controlled from an interlocked sheet steel cubicle switchboard which houses the incoming isolator, winder motor isolators, main spring-operated oil circuit breaker rated at 800 amps., 250 MVA and equipped with no-volt and shunt trip coils and overcurrent and earth-leakage relays and a 400 amp. non-automatic oil circuit breaker for the supply to the auxiliary trans-

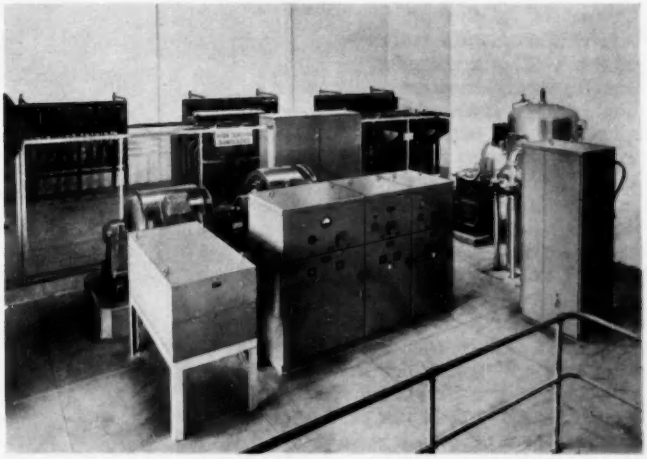

Fig. 8.—General arrangement of the control equipment. In the foreground are the control unit, contactor cubicles for the motor generator and fans and starting panel for the compressor.

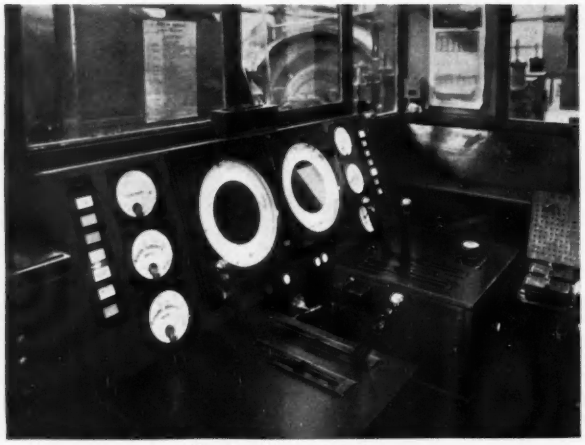

Fig. 9.—Control desk.

former. The stator reversing and dynamic braking contactors (fig. 7) are fully interlocked and arranged for solenoid operation, while air-cooled unbreakable grids form the rotor resistance unit and are adjusted by electro-pneumatically operated contactors mounted on an open framework (fig. 7). Each phase of the rotor resistance is cooled by two 38 in. aerofoil fans. For normal operation, which includes dynamic braking, only one fan operates, but if reverse current braking is used the second fan starts up automatically to dissipate the additional heat generated in the resistance bank.

A 110 h.p. motor generator seen in the foreground of fig. 7 supplies the D.C. excitation to the stators of the winder motors for dynamic braking, and is arranged for direct-to-line starting, its control gear being mounted in a cubicle together with that for the ventilating fan motors. The general disposition of the control gear is shown in fig. 8.

Each winder is operated from a remote control desk (fig. 9) on which are mounted the operating levers, speed and depth indicators, instruments, indicating lamps, circuit breaker control switch, start and stop push buttons for the motor generator and fan motors and an emergency stop button.

THE DYNAMIC BRAKING AND CONTROL SYSTEM.

From the electrical viewpoint, the main interest of this installation centres round the method of control and dynamic braking employed. It is a closed loop system and in this instance is arranged to give accurate torque control, but it can also be designed for speed control and thus is particularly suitable for fully automatic winders.

The principles which led to its development formed the subject of an article in an earlier issue of this Journal.* In that article it is shown that:

(1) For dynamic braking the optimum torque, independent of speed, at any given degree of excitation is developed when: Rotor circuit resistance = speed $\times K_1$ (a constant).

(2) For driving or reverse current braking the torque will be constant and independent of the speed if: Rotor circuit resistance = slip $\times K_2$ (a constant).

From the foregoing it will be seen that by adjusting the constants K_1 and K_2, the maximum or any selected torque can be maintained at all speeds with optimum performance of the plant.

* *G.E.C. Journal*, Vol. XVI, No. 4, October, 1949.

Fig. 10.—One of the 4,200 h.p. winders, showing in the foreground the control generator which is chain-driven from the winder motors.

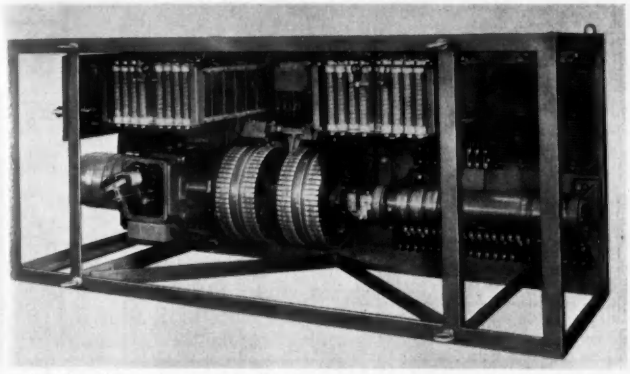

Fig. 11.—Control unit with all covers removed to show the disposition of the components.

Automatic variation of the rotor circuit resistance to comply with the above requirements is effected through the medium of an oil servo mechanism, the operating valve of which is governed by two control coils, acting in opposition to each other. The coil which causes the resistance in the rotor circuit to be reduced is excited at constant voltage and so exerts a constant pull. The other serves to insert resistance and is excited from a control generator which is chain-driven from one of the winder motors. It is seen in position in fig. 10, and feeds the control coil through a variable transformer actuated by the driver's lever, and an adjustable resistance which is varied automatically so that it bears a constant relationship to the resistance in the rotor circuit of the winder motors.

The oil servo mechanism is seen on the left of fig. 11. The two contact drums in the centre adjust the value of the resistance in the circuit of the variable pull control coil, while the drum controller at the right actuates the main rotor resistance contactors. The complete assembly forms a totally enclosed unit.

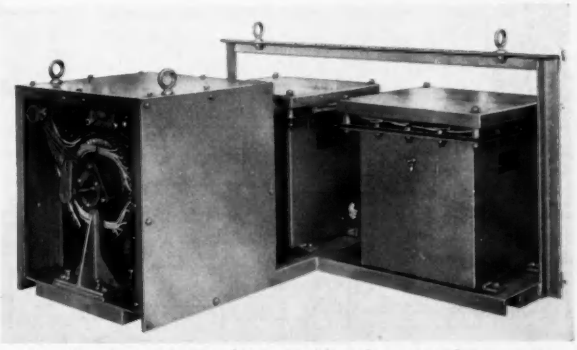

Fig. 13.—Arrangement of the variable voltage transformer unit.

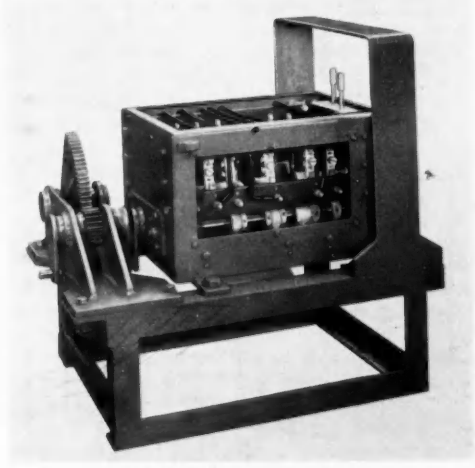

Fig. 12.—Master controller.

Immediately below and operated by the driver's lever, are the master controller (fig. 12) and the variable voltage transformer and field regulator for the dynamic braking generator (fig. 13).

OPERATION.

The operation of the control system may be followed by reference to the simplified schematic diagram (fig. 14). Consider first the sequence which occurs when winding. When the winder is at rest all the rotor resistance R and control coil resistance r are in circuit. A small initial movement of the driver's lever causes the forward or reverse contactors to close, and connect the stators of the winder motors, $WM1$ and $WM2$, and the rotor of the control generator CG to the 3-phase supply, so that the voltage induced in the stator of the generator CG will be proportional to the slip. At the same time the coil LR is energised from the constant voltage supply.

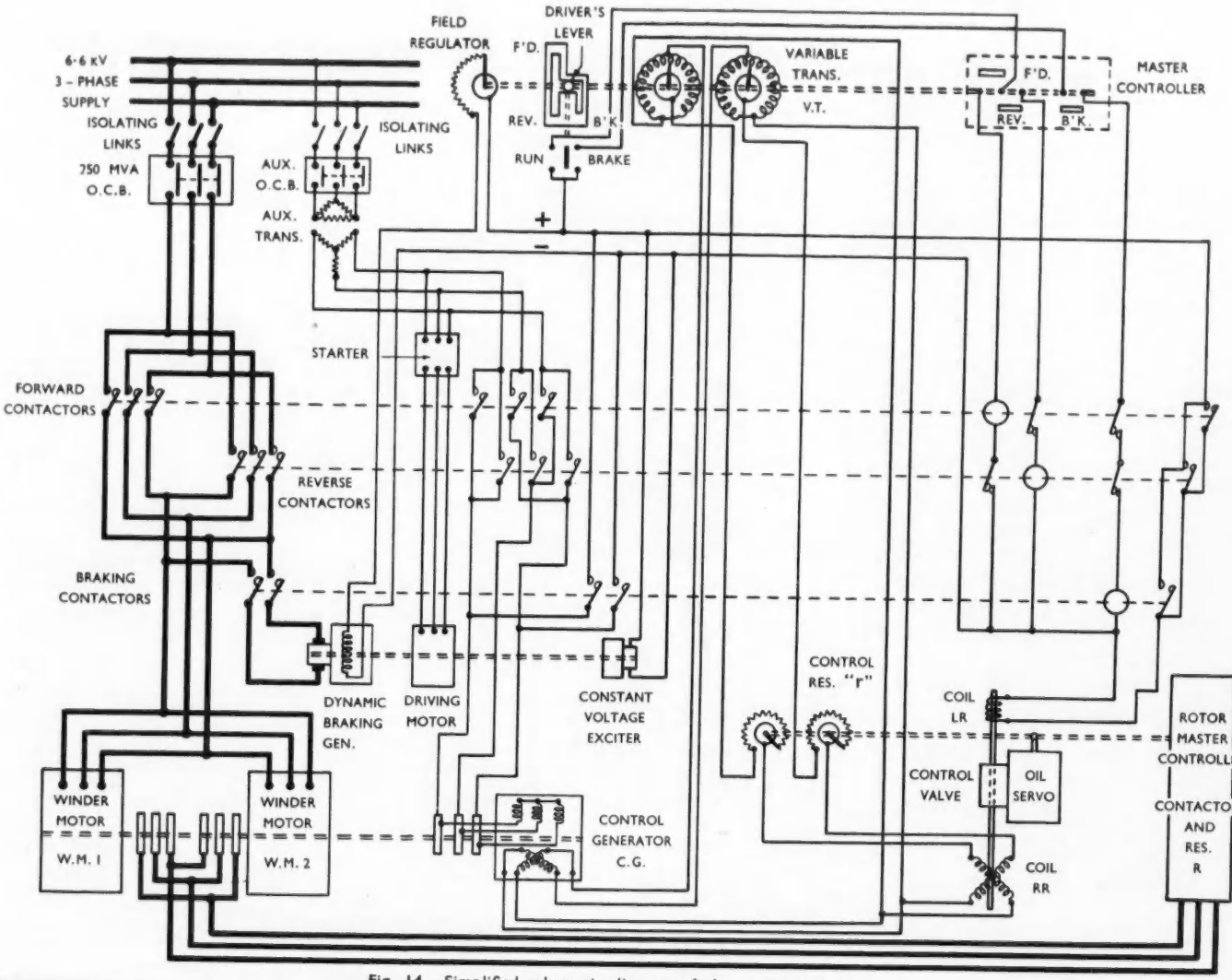

Fig. 14.—Simplified schematic diagram of the control scheme.

At the instant of starting, the voltage of the control generator *CG* is at its maximum and consequently the voltage applied to coil *RR* is such that this coil takes control and thus retains the rotor resistance *R* at its maximum value. Further movement of the driver's lever alters the tapping on the variable transformer *VT* and so reduces the voltage across the coil *RR* so that the coil *LR* takes control and reduces the rotor resistance *R* until its value corresponds to the torque represented by the lever position. Simultaneously, it reduces the value of *r* and so increases the pull of the coil *RR* until it balances that of the coil *LR* and the servo mechanism is brought to rest. Thus the resistance *R* is adjusted without delay to suit the chosen starting torque and thereafter slowly decreases automatically as the voltage of the control generator decreases with increasing speed until the resistance *R* is at its lowest value and the winder motors reach full speed.

The control gear is equally effective in regulating the value of the rotor resistance *R* and the torque during reverse current braking.

As the wind proceeds the weight of the overhanging rope overbalances the load so that the winder tends to accelerate and weak dynamic braking is applied with the driver's lever in its first braking position in order to keep the speed constant. As the lever is moved to dynamic braking, the running contactors are opened and the dynamic braking contactors closed so that the stators of the winder motors, *WM*1 and *WM*2, and the rotor of the control generator *CG* are excited with direct current. Thus the voltage of the control generator becomes directly proportional to the speed of the winder motors.

At the instant of applying weak dynamic braking, the winder is normally running at its maximum speed and the control generator *CG* and the variable transformer *VT* give maximum voltage, but the D.C. excitation of the stators of the winder motors is at its minimum. However, since the driver's lever had to pass through the neutral position, the rotor resistance *R* and the control coil resistance *r* will have moved towards their maximum values, and as soon as the dynamic braking contactors close, the opposing pulls of the coils *RR* and *LR* will adjust the values of the resistances *R* and *r* until the control circuit is restored to a state of balance. At this stage the resistance *R* is at its optimum value corresponding to the excitation of the winder motors and their momentary speed.

Near the end of the wind, the driver's lever is moved to its full braking position and maximum dynamic braking is applied. At this instant, the winder is still running at approximately full speed so that the control generator *CG* is giving maximum voltage. At the same time the position of the driver's lever is such that the variable transformer *VT* gives a reduced voltage and maximum excitation is applied to the stators of the winder motors. The coil *LR* takes control and reduces the control resistance *r* and rotor resistance *R* until their values correspond with the requirements of excitation and speed.

As the speed of the winder drops due to the braking effort, the voltage of the control generator *CG* decreases so that the current in the coil *RR* falls and the coil *LR* again reduces the rotor resistance. Thus the braking effort is maintained independently of speed until finally the rotors are short-circuited and the winder is brought almost to rest so that it can be stopped accurately at the decking position by the mechanical brakes.

Fig. 14.—Simplified schematic diagram of the control scheme.

OUTSTANDING FEATURES.

It will be appreciated from the foregoing that this system of control possesses certain outstanding features which may be summarised as follows:

(1) When either winding or braking dynamically, the maximum permissible torque cannot be exceeded however the driver's lever is operated so that there is no fear of overstressing the plant. Furthermore, the maximum torques for driving and for dynamic braking can differ if desired.

(2) The extent to which the driver's lever has been moved from the neutral position determines the value of the torque applied either for driving or dynamic braking.

(3) When using dynamic braking, the resistance in the rotor circuit is always at its optimum value, so that the currents flowing in the stator and rotor windings are as small as possible and losses and heating are thus minimised.

(4) Excessive movement of the driver's lever cannot result in a reduction of the braking torque.

(5) Long periods of braking at low speed, as required for shaft inspection, can be undertaken with a minimum of heating of the winder motor.

(6) Maximum braking torque can be maintained down to very low speeds.

ACKNOWLEDGMENT.

Acknowledgment is due to the Anglo-American Corporation of South Africa for permission to publish information from their magazine, *Optima*, describing the general development of the mining area.

Sugar Factory Electrification in British Guiana

By H. S. WILSON, A.M.I.E.E.
Chief Electrical Engineer, Booker's Sugar Estates, Ltd., Georgetown, British Guiana.

INTRODUCTION.

AT the conclusion of the second World War the sugar industry in British Guiana was faced with the necessity of rehabilitating and modernising its sugar factories which had suffered from shortages of both machinery and staff.

The firm of Booker Brothers, McConnell & Co., London,* which has controlling interests, as owners or agents, in ten sugar factories, realised that the time was ripe for a substantial measure of electrification. Previous to the war, two factories in the group had been modernised and a considerable proportion of the auxiliary machinery was electrically driven, but the lighting and the domestic electric supply to the staff dwelling-houses belonging to these, and to the other eight factories, was still obtained from small D.C. generators.

The programme has involved almost the entire replacement of the old steam-driven auxiliaries by electrically-powered machinery in three of the factories, together with the installation in each of a complete generating station comprising turbo-alternators, a diesel-alternator set and the necessary switchgear. Incidentally, the names of these three sugar estates: Port Mourant, Uitvlugt and Rose Hall, throw an interesting sidelight on the history of the Colony of British Guiana, which was at various times in the hands of French and Dutch settlers before becoming a British possession.

In all seven of the remaining factories, A.C. power plants have replaced the D.C. units, and gradually the existing auxiliary machinery is

* This firm now operates the sugar plantations and factories in British Guiana through its subsidiary, Booker's Sugar Estates Ltd., Georgetown, British Guiana.

Fig. 1.—Trains of steel punts bringing sugar cane to the factory.

Fig. 2.—Bundle of cane being loaded on to the weighing machine.

being superseded by electrically-operated equipment.

SUGAR ESTATES.

Sugar cane in British Guiana is grown on the coast lands within an area about eight miles wide along the Atlantic seaboard. The estates, or plantations, are located at irregular intervals, the farthest being situated, one on the Corentyne River which borders on Dutch Guiana, and the other 130 miles to the west. In the intervening territory are extensive areas of rice lands, some coconut plantations, small general farms and grazing areas. The whole of the coastal belt is quite flat and mostly below sea level at high tide. These features necessitate, throughout the Colony, an enormous system of sea defences, drainage and irrigation canals. Cane is transported by water and is carried in steel punts each capable of holding up to 10 tons, though the normal loading is considerably less than this. Trains of punts are hauled to the factory by mules or tractors (fig. 1).

PREPARATION OF THE SUGAR CANE.

The factory at Uitvlugt has been taken as typical and it is there that the greatest changes have been made. The description that follows, as well as the illustrations, refer to this factory, though the process is substantially the same in all the other factories.

On arriving at the factory the punt loads of

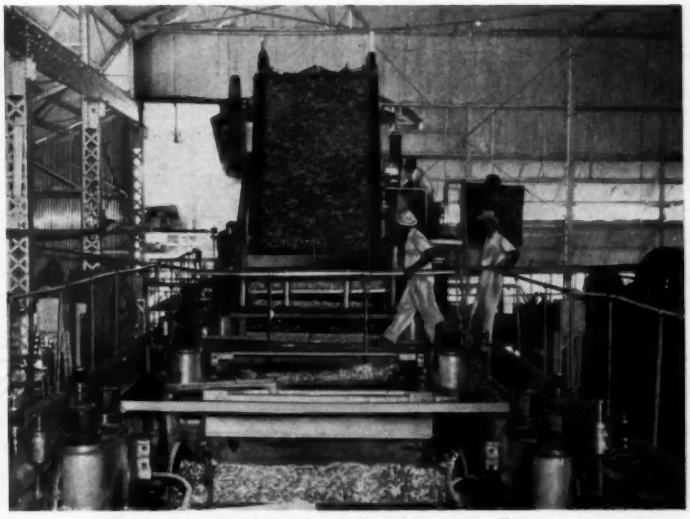

Fig. 3.—Feeding cane into the mill.

Fig. 4.—Bagasse being elevated to the boiler house carrier.

cane are lifted out bodily by means of chains which are laid across the punt before it is loaded.

Fig. 2 shows the cane hoist about to deposit a bundle on to a scale for weighing, while a group of punts is waiting to be unloaded. From the scale the cane is allowed to slide on to a carrier which takes it up to the mill entrance. On its way the cane passes two sets of revolving knives which are set across the carrier and cut the greater part of the cane into small pieces, thus making it easier to feed into the mill. The first set of knives, which is driven by a 30 h.p. motor, is set higher above the floor of the carrier than the second set which is driven by a 250 h.p. slipring machine running at 720 r.p.m.

The mill itself consists of a series of cast-iron rollers, between successive pairs of which the cane is crushed, the fibre being fed from one set of rollers to the next by intermediate carriers while the juice which is squeezed from the cane falls into the mill bed from where it is pumped away for processing. Fig. 3 shows the cane being fed into the mill, while the last two mills are seen in fig. 4 with the residue of cane, known as " bagasse ", being elevated to the boiler house carrier. The vapour seen rising from the bed of cane is from hot imbibition water which is poured on to the cane to increase the juice extraction. The bagasse is conveyed by an elevator to a carrier which runs along the length of the boiler house, above the furnaces, and is fed to them through gates having variable openings. It is noteworthy that this bagasse supplies the entire fuel requirements of the factory during grinding, providing steam for the power plant, mill engines and some of the auxiliary engines, as well as process steam for evaporating the juice and boiling the sugar. Surplus bagasse is stored in a " logie ", which forms an extension to the boiler house, and can be returned for use during periods of reduced grinding and when starting up the factory. In some of the factories excess bagasse is baled and used in nearby drainage pumping stations, or stored to meet future requirements.

There are three main boilers, of the suspended arch type, manufactured by John Thomson, Ltd., each of 6,030 sq. ft. heating surface and operating at 180-200 lb./sq. in. All three boilers are fitted with forced and induced draught fans, two being equipped with automatic controls to

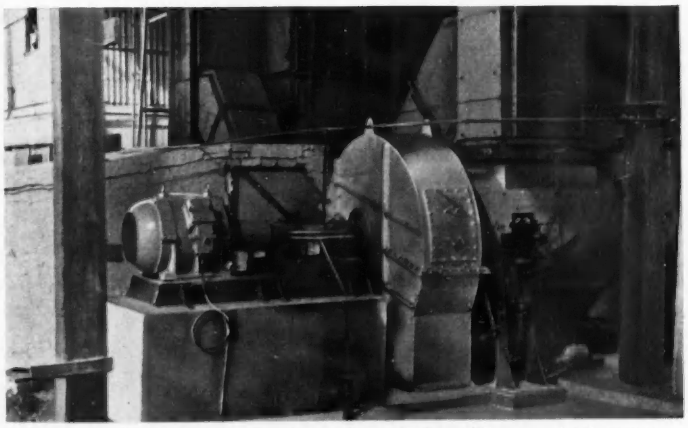

Fig. 5.—Induced draught fan driven by a 30 h.p. 725 r.p.m. high torque squirrel cage motor.

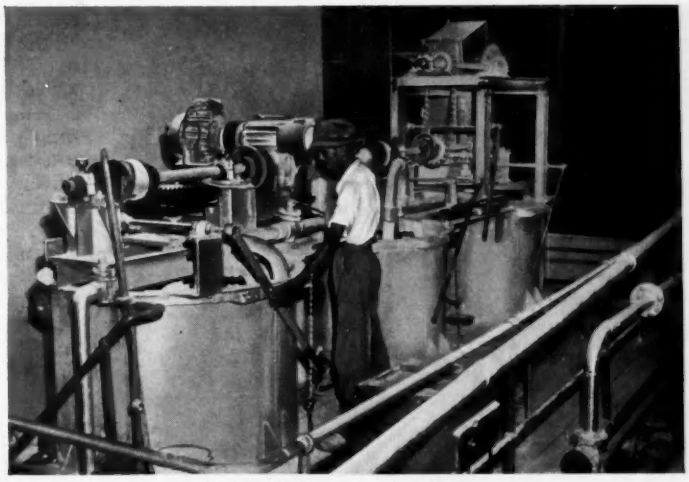

Fig. 6.—Milk of lime mixing plant.

maintain full boiler pressure and a condition of balanced draught with a combustion chamber pressure of 0·1 to 0·2 in. water gauge. The induced draught fans, one of which is seen in fig. 5, are driven by 30 h.p. high torque squirrel cage motors, and the forced draught fans by 15 h.p. squirrel cage machines. On No. 3 boiler the forced draught is provided by two 2-stage aerofoil fans supplied by Woods of Colchester.

MANUFACTURE OF SUGAR.

The juice from the sugar cane is pumped from the mill to an automatic weighing machine and thence to a mixer where milk of lime is added. The limed juice is then pumped through heaters to a continuous clarifier where the solid impurities, or "muds", settle and the clear juice is drawn off for further treatment. The lime mixing plant is seen in fig. 6. The muds are fed to a continuous rotary vacuum filter, where most of the sucrose residual in the mud is recovered and returned to the clarifier, while the mud is dumped into a cane punt and returned to the fields as a valuable fertiliser.

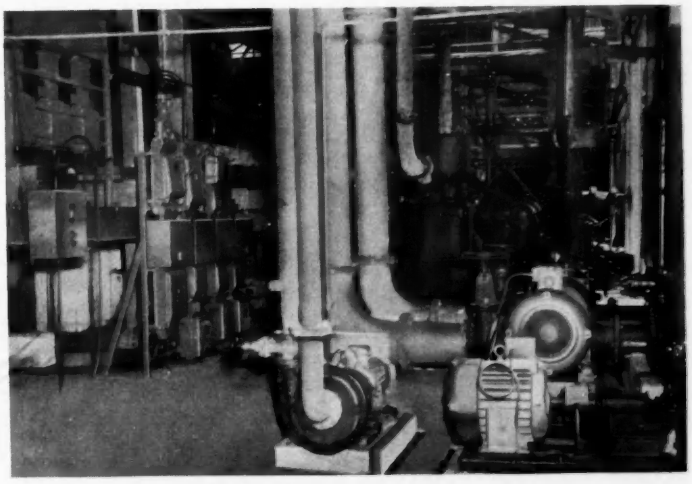

Fig. 7.—Water pumping station.

Fig. 8.—Part of the pan floor.

The clear juice drawn from the clarifier is passed on to a multiple effect evaporator where it is concentrated to a syrup. Boiling takes place in the evaporator in a series of five vessels; in the first of these the juice is under a slight positive pressure and is boiled by exhaust steam. The vapour from the boiling juice in this vessel passes over to the steam space of the second vessel, while the juice space of this vessel is under a slight vacuum, so that here boiling takes place with vapour obtained from the juice in the first vessel. This process is repeated a third, fourth and fifth time, the juice passing at each stage into a vessel with a progressively higher vacuum until finally it is in the form of syrup. A group of pumps, with their switches and starters mounted together on a sub-distribution board, is seen in fig. 7.

The syrup is now stored in tanks to await the boiling process in which the crystals are formed. This takes place in vacuum pans, which are vessels of similar construction to the evaporators. In other tanks is stored the high-grade molasses, which is syrup from which some sugar has already been extracted.

A mixture of fresh syrup and molasses is drawn into the pan and boiled and, at the critical moment in this operation, small crystals form which provide the "grain" on which the final crystals grow by deposition of sugar from the boiling liquor. In fig. 8 is seen part of the pan floor with the pans on the left and one of the

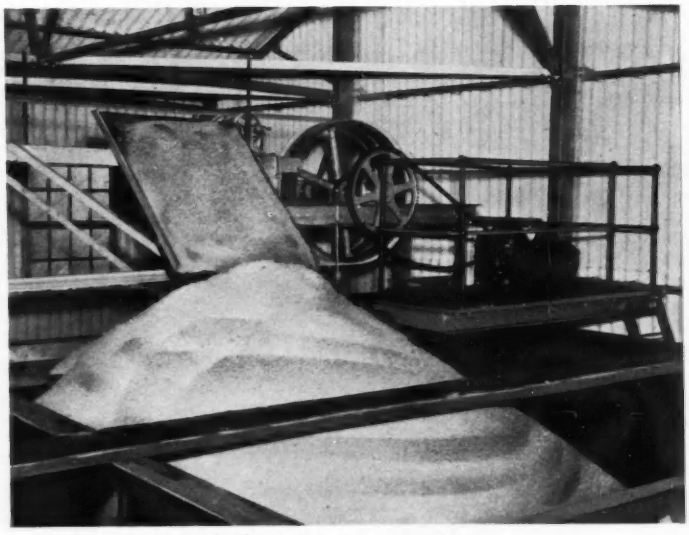

Fig. 9.—Sugar conveyor and bin.

syrup tanks on the right. When the crystals have attained the desired size the boiling is stopped and the contents of a pan are discharged into a crystalliser, which is an open vessel with slowly revolving water-cooled paddles in which the mixture of molasses and sugar crystals, known as massecuite, cools gradually, and in which the crystals continue to grow.

The separation of the crystals from the molasses takes place in vertical centrifuges consisting of individually motor-driven baskets revolving in an outer casing. The basket has perforated walls lined with fine brass or copper mesh through which the molasses is driven by centrifugal force, while the crystals are retained on the walls of the basket. After the sugar has been washed with water, followed by a further period of spinning to dry it, the basket is stopped and the sugar discharged through a gate at the bottom of the basket. It is taken, by a series of conveyors and elevators, to bins from which it is bagged, weighed and stored to await shipment (figs. 9 and 10). The molasses drains from the outer casing of the centrifugals to a pump which returns it for reboiling along with the fresh syrup, or, in the case of molasses which has already been boiled twice, pumps it into the distillery for making rum.

Fig. 10.—Bagged sugar being put into storage.

ELECTRICAL EQUIPMENT.

Two geared turbo-alternators provide the power required to drive all the machinery except the mills, cane carrier and the vacuum pumps which exhaust the air and incondensable gases from the evaporators and vacuum pans. The turbo-alternators are rated at 720 kVA, 0·75 power factor, and generate at 420 volts, three-phase, 50 cycles. The turbines run at 6,000 r.p.m. and drive the alternators through speed-reducing gears at 1,500 r.p.m. Steam is supplied at 180 lb./sq. in., 500 degs. F. and is exhausted to a back-pressure main at 15 lb./sq. in. For the sugar-making process the exhaust steam from the turbines and existing steam engines is used, together with live steam from the boilers fed through a reducing valve. The electric supply throughout the factory is at 415 volts, three-phase for power, the lighting supply being provided through transformers and distributed on a 120/208 volt 4-wire system.

The power house (fig. 11) is a two-storey building, the ground floor of which houses air filters, oil coolers and other auxiliaries. Provision is made for a third turbo-alternator and, for starting up the factory and for week-end and off-season running, there is a diesel-alternator rated at 250 kVA, 0·8 power factor, 420 volts, 428 r.p.m. comprising a Bellis and Morcom diesel engine directly coupled to the alternator. In this case, also, provision is made for the later addition of a second diesel-alternator set.

The main switchboard in the power house is of all-metal construction and, besides the alternator control panels, includes feeder panels which control the supply of power to the sub-distribution boards situated at various convenient centres. Each alternator panel is fitted with a

voltage regulator, to permit parallel running, and a battery-operated reverse power relay.

The feeder circuits are supplied through oil-immersed breakers all of which are interchangeable with one another, the only difference in the panels being that, for operating the meters and trip coils, some are fitted with 400/5 and others with 200/5 current transformers.

All feeder cables are 0·2 sq. in. paper insulated, lead-covered, single wire armoured, one cable being used for the 200 amp. circuits and two in parallel for the 400 amp. circuits. There is thus maximum interchangeability of equipment, necessitating only a minimum of spares. Also, the cable is kept to a size that can be handled fairly easily by unskilled labour. In this connection it is of interest that the whole of the installation at these factories has been carried out with unskilled and semi-skilled labour with but little supervision, and it was thus of importance to arrange that the installations should be as simple as possible. Each of the switchboards at Uitvlugt, Port Mourant and Rose Hall includes an incoming and outgoing feeder panel for the possible future interconnection of either, or all, of these factories with others not too far distant.

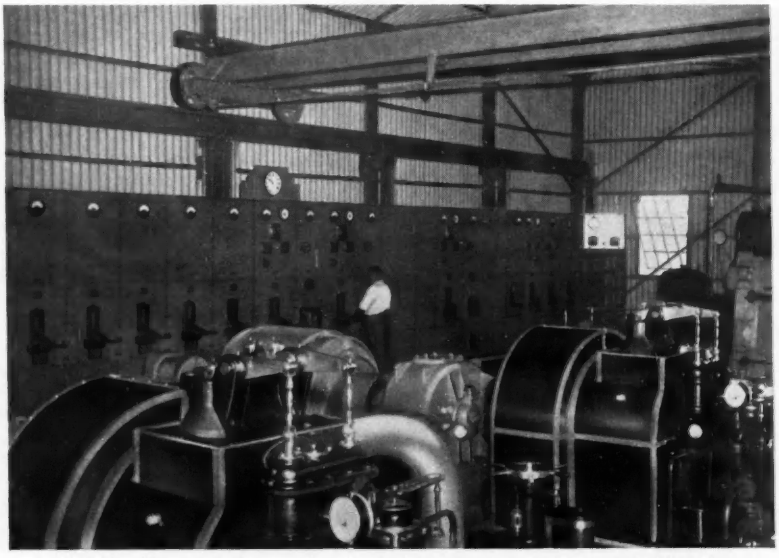

Fig. 11.—The power house, showing turbo-alternators and main switchboard.

In addition to the turbo-alternators, diesel alternator sets, transformers, switchgear and cabling already mentioned, there has been supplied a total of over 300 motors ranging from 1 h.p. to 250 h.p. aggregating 2,900 h.p., together with their associated starting and control gear. At Uitvlugt, about 100 motors totalling 1,500 h.p. are installed.

ACKNOWLEDGMENT.

Thanks are due to Booker's Sugar Estates, Ltd. for permission to publish the foregoing information, and to Mr. J. Eisner for his valuable help in its preparation.

A New Vector Slide Rule

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(1) INTRODUCTION.

THE ordinary logarithmic slide rule used so widely for multiplication, division, power and root calculations is limited to scalar, i.e. uni-dimensional quantities. It is not possible to carry out directly with it calculations referring to 2-dimensional relations, such as those between vectors and complex numbers, without much intermediate calculation on paper, because these always involve combinations of addition and subtraction, multiplication and division. Division of complex numbers is particularly tedious due to the need for first multiplying the numerator and denominator by the conjugate of the complex denominator.

The object of the vector slide rule is to simplify calculations of this kind, and to reduce the amount of intermediate writing necessary in the solution of a numerical equation, or in simplifying an equivalent electrical network as much as possible. Its most direct application in electrical engineering will be for the quick conversion of resistance and reactance into impedance and phase angle. These relations can be read directly on the vector slide rule. In addition, the vector slide rule is designed to make a short cut through many of the tedious transformations necessary in the analysis of real and complex electrical networks by a convenient combination of direct and reciprocal scales.

(2) BASIC PRINCIPLE.

The present attempt is based mathematically on the same fundamental principle which was first developed by J. Spielrein[1] and has recurred in similar attempts by various later authors [2, 3, 4].

The principle may be understood directly from the logarithm of a complex operator, say, an A.C. impedance :

$$\dot{Z} = R + jX = Z.\epsilon^{j\phi} = Z\,(\cos\phi + j\,\sin\phi) \quad (1)$$

where R is the real component (resistance) and X the imaginary component (reactance) in the Gaussian plane, with $j = \sqrt{-1}$ indicating the phase displacement of 90° between real and imaginary components. The absolute magnitude of the operator $\dot{Z}$ is Z and its phase displacement relative to the real axis ϕ. If now, for simplicity, the natural logarithm of $\dot{Z}$ is taken, using the second equation (1) we have, since $\log \epsilon^x = x$

$$\log \dot{Z} = \log Z + j\phi \quad (2)$$

This is another complex number which can be demonstrated as a vector with log Z on the real and ϕ (linearly) on the imaginary axis and since $R = Z \cos\phi$ and $X = Z \sin\phi$ (see e.g. equ. (1)) it follows at the same time that

$$\log Z = \log R + \log \frac{1}{\cos\phi} = \log X + \log \frac{1}{\sin\phi} \quad (3)$$

Equation (3) shows first a simple interrelation between the 2 pairs of numbers (R and X, Z and ϕ) which define a given operator $\dot{Z}$. This interrelation is illustrated in fig. 1 for an arbitrary example of R and X. Obviously if two curves $\phi_1\left(\log \frac{1}{\cos\phi_1}\right)$ and $\phi_2\left(\log \frac{1}{\sin\phi_2}\right)$ are plotted but shifted relative to the origin of the diagram by $\log R$ for ϕ_1 and by $\log X$ for ϕ_2 then these two curves will, in accordance with equation (3), intersect at a point for which $\phi_1 = \phi_2 = \phi$ ($\log Z$).

(3) PRACTICAL DESIGN OF THE SLIDE RULE.

Though the same fundamental relation is at the root of the present development it appeared possible to widen its usefulness by some expansion of the principle. The resulting new slide rule is shown in fig. 2.

There are two pairs of curves, namely, the contours of two templates which can be shifted by movement of two normal slides to which they are fixed. The left-hand contours represent the functions ϕ_1 and ϕ_2 and attention may first be paid to these alone. A linear ϕ scale is shown on the blade attached to the cursor. The main scales involve three logarithmic decades and

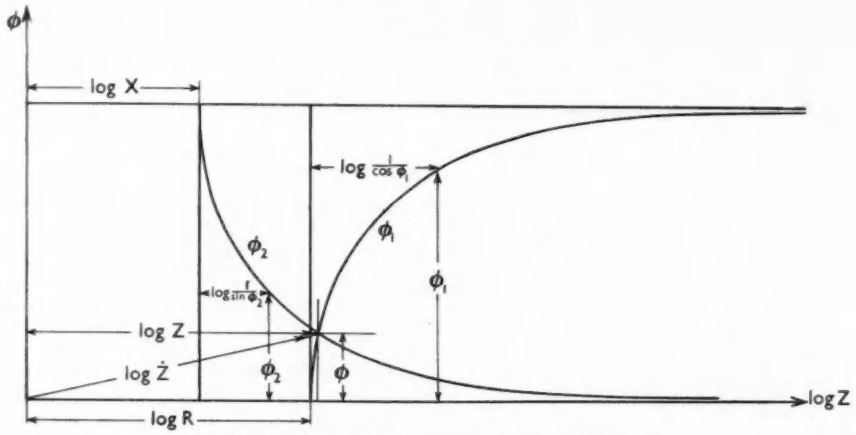

Fig. 1.—Fundamental relations of the vector slide rule.

their reciprocals. They are repeated three times, once for each template slide and once for the normal slide rule at the bottom of the instrument.

With these scales it is possible to read directly Z and ϕ if the templates are shifted with their base marking lines to R and X by adjusting the cursor so that the vertical angle scale line coincides with the intersection between the left-hand contours. The hair line on the bottom part of the cursor then shows Z and the vertical angle scale shows the phase angle ϕ.

The right-hand contours give the same functions ϕ_1 and ϕ_2 but with reference to the lower logarithmic scale which involves only $1\frac{1}{2}$ decades, i.e. is the square root of the (upper) main scales. That means that with reference to the upper scales the corresponding functions are

$$\phi_3\left(log\frac{1}{cos^2\phi_3}\right) \text{ and } \phi_4\left(log\frac{1}{sin^2\phi_4}\right)$$

The origin of the right-hand contours is for practical reasons shifted by one decade relative to that of the left-hand contours.

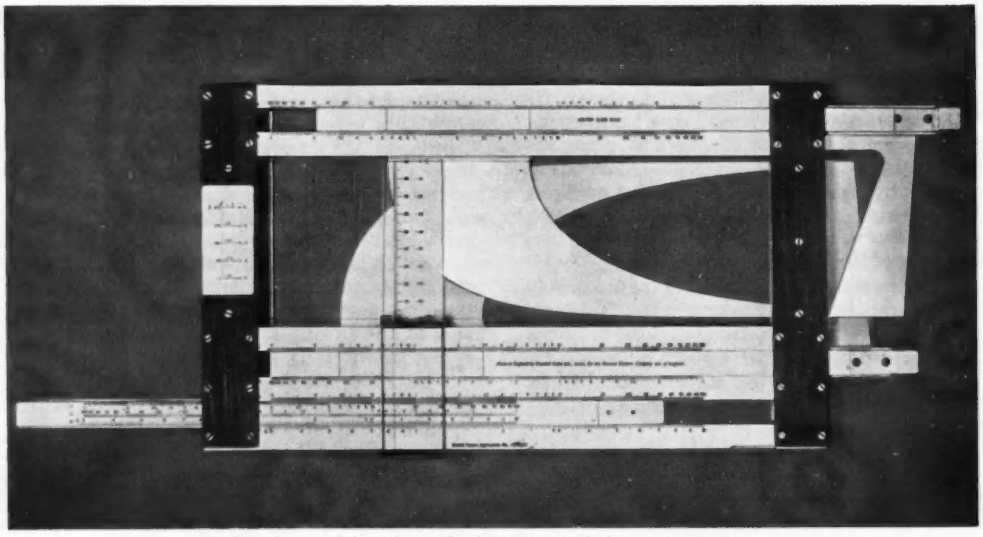

Fig. 2.—Vector slide rule set for impedance/admittance conversion.

The angle scale is extended over 90° only, but a convenient quadrant scheme fixed to the frame gives an easy survey over the range of angles and scales to be used if one or both of the real and imaginary components of a complex operator are negative.

The bottom part contains a slide on which both the upper (3 decade) scale and its reciprocal, and the lower (1½ decade) scales are repeated as on an ordinary slide rule but extended over a greater decade range.

(4) MAIN APPLICATION OF THE SLIDE RULE.

It is not possible to give here a full account of the application of the slide rule beyond an explanation of the kind of operation involved with the main applications proposed.

The evaluation of Z and ϕ from R and X which involves two template adjustments and the final cursor movement and reading of the result, at the same time solves, of course, the simple equation $Z = \sqrt{R^2 + X^2}$ or by simple expansion quite generally $A = \sqrt{A_1^2 + A_2^2 + A_3^2 + \ldots}$

If the same operation is carried out with respect to the right-hand contours the solution of

$$A = A_1 + A_2 + A_3 + \ldots$$

will result, i.e. the slide rule can be used as a simple adding (and, of course, subtracting) instrument. Since, however, the result appears on a logarithmic scale it may be used directly for further multiplications and divisions on the bottom slide rule or in conjunction with other manipulations.

If the reciprocal scales are used in conjunction with the right-hand contours one can read directly

$$\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \ldots$$

i.e. for instance the resistance r resulting from the parallel connection of an arbitrary number of resistances $r_1, r_2, r_3 \ldots$

A time-saving use of the instrument will be for conversion of series impedances into parallel admittances. Assume for instance a resistance R and a reactance X in series are given for which the equivalent conductance g and susceptance b in parallel must be found for simplification of an A.C. network involving parallel impedances.

$$\text{If } R + jX = \dot{Z} \text{ and } g - jb = \left(\frac{1}{\dot{Z}}\right)$$

it is known that

$$g = \frac{R}{Z^2} \text{ and } b = \frac{X}{Z^2} .$$

In this form parallel circuits may be added arbitrarily and then converted back into the impedance form. The solution by the vector slide rule involves only a shift of the bottom slide to the position where the movable inverse scale shows the same value of Z under the hair line of

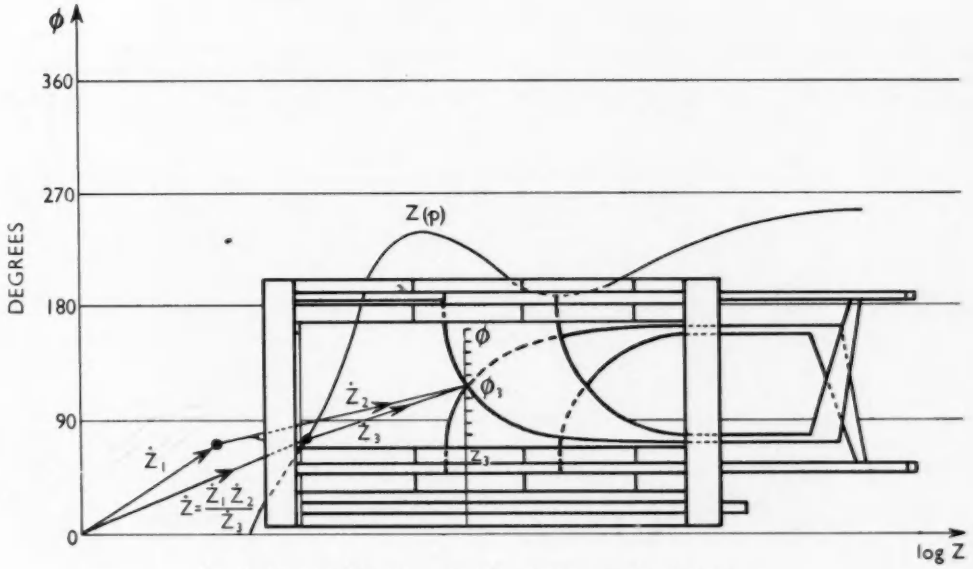

Fig. 3.—Vector slide rule as used for plotting response functions.

the cursor as read on the main scale. g and b may then be read under R and X on the normal (3-decade) scale of the bottom slide. Fig. 2 shows the slide rule adjusted for this evaluation for the following numerical example.

$$R = 0{\cdot}295 \qquad X = 0{\cdot}640 \qquad Z = 0{\cdot}705$$
$$g = 0{\cdot}595 \qquad b = 1{\cdot}29$$

The reciprocal scales actually show a numerical value 10 times the reciprocal value of the direct scale as usual for convenience. The factor 10 may, however, in this calculation be ignored because it drops out again when the admittances are converted back into impedances. This back conversion is made in exactly the same way as the opposite conversion.

Another object of the development of the vector slide rule was to simplify the work involved in the multiplication and division of complex transfer functions, particularly for the plotting of frequency response diagrams on the drawing board as required for the stability analysis of closed loop control systems. This application is demonstrated in fig. 3. It is based on equation (2) and the general rule that, on a logarithmic scale, multiplications are converted into additions, which applies equally to real and complex numbers. Thus, by adding or subtracting vectors representing the logarithm of complex numbers, the logarithm of their product or quotient is obtained on the same scale. For the purpose of this application the slide rule is fitted with suitable base marking lines at the left inside of the main frame from which now logarithmic vectors $\dot{Z}_1$, $\dot{Z}_2$, $\dot{Z}_3$ can be drawn to the point of intersection between the template contours, added and subtracted by simply shifting the slide rule from point to point preferably using ruled paper or a parallel shifting device.

To summarise, the vector slide rule promises to be helpful for the following applications :

1. Conversions between pairs of constants defining a complex number.
2. Quadratic addition and subtraction of scalar numbers and their reciprocals under the square root.
3. Linear addition and subtraction of scalar numbers and their reciprocals.
4. Conversion of series impedances into parallel admittances and vice versa.
5. Multiplication and division of complex numbers, particularly for network transformation, plotting of transfer functions, etc.

All calculations may be combined with ordinary slide rule manipulations.

ACKNOWLEDGMENT.

The author wishes to acknowledge the help received from his colleague, Mr. K. C. Parton, who took an active part at all stages of the work involved, and the help of the Switchgear Works Experimental Section, who produced the first prototype and the precision master pattern for the production templates. The final result, however, is largely due to the active co-operation and useful suggestions contributed by the manufacturers of these slide rules.*

* Blundell Rules, Ltd., Chaul End Lane, Luton, Beds.

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Fluorescent Lighting in Ocean-going Liners

By C. DYKES BROWN, A.M.I.E.E., F.I.E.S., and G. ROBINSON, A.M.I.E.E.
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INTRODUCTION.

CONSIDERABLE advances have been made in the lighting of public rooms of ocean-going liners since the first cold cathode fluorescent lighting tests were pioneered by the G.E.C. on board ship in 1936. At that time fluorescent tubes of the cold cathode type were being used in a small number of buildings, particularly for lighting of a decorative character. The principal features of this comparatively new illuminant included (*a*) a much longer life than that of any other lamp available, (*b*) a wide range of colours which enabled decorative effects to be obtained more efficiently than by using coloured tungsten filament lamps or colour filters, and (*c*) the tubes could be shaped or curved to conform to the architectural requirements of room interiors. It was not surprising that a light source with such advantages was soon considered for lighting in public rooms of ships.

There was, however, much diffidence about its adoption as queries were immediately raised in view of the method of operation. It was only after extensive trials had been carried out in a coastal vessel that it was agreed that (*a*) the alternating current and high voltages used did

Fig. 1.—Glazed cornices concealing cold cathode tubing in the Empress of Scotland.

not present any great difficulties, (*b*) the apparatus did not interfere with the performance or accuracy of direction-finding equipment, and (*c*) there was no interference with radio transmission or reception.

The success of these trials was followed during the next two years preceding the war by installations in several ships. Among these were R.M.S. Queen Mary and the Dutch liner M.V. Oranje. Architects responsible for interior planning of public rooms of new ships designed the ceilings so as to take full advantage of the facilities offered by the cold cathode fluorescent tube.

A typical example was the Social Hall of the Oranje where the ceiling was shaped to conceal a three-colour lighting system. The fluorescent tubes were capable of being controlled automatically to produce a wide range of colours in a continuous cycle.

During the war fluorescent tubes of the hot cathode type were introduced but several years elapsed before they were used in marine installations.

An increased interest is now being shown in the application of both hot and cold cathode fluorescent tubes and in this article the authors describe and compare these when used for ship lighting.

Fig. 2.—A happy combination of tungsten filament and fluorescent lighting in a lounge of the Ocean Monarch.

ADVANTAGES OF FLUORESCENT LIGHTING.

(*a*) Importance of Glare-free Illumination.

The low ceiling height which usually obtains on board ship invariably necessitates installing a lighting system which is well within the normal field of view. Ceiling heights of between 7 ft. and 8 ft. frequently occur in public rooms, entrance halls and alleyways of medium-sized liners and particular care has to be exercised to avoid brightness from the lighting which is sufficient to cause distraction or discomfort. For many years it has been the practice to screen filament lamps by translucent shades to shield the source of light from the eyes and at the same time provide decorative features. Another method of avoiding bright light sources and of obtaining well-diffused shadow-free illumination has been to use indirect lighting with the lamps totally concealed.

The introduction of fluorescent tubes, with low surface brightness, has contributed more towards lighting progress than any other light source since the advent of the filament lamp. Not only are they admirable for indirect cornice lighting, but their low surface brightness enables them to be installed behind lightly diffusing glassware for semi-direct lighting systems (fig. 1).

(*b*) Luminous Efficiency.

The provision of good ship lighting has to be effected with reasonable economy, from the point of view of fuel consumption, generator size and installation costs. It is interesting to compare lighting loads using fluorescent or filament lamps for a typical indirect lighting system. For approximately the same lumen output per foot run of cornice, a cold cathode or hot cathode installation using tubes which provide a warm quality of light would constitute about one quarter of

the load taken by 25 watt filament lamps at 6 in. centres. This saving obtained by the use of fluorescent tubes is reflected in the size of the generating plant.

(c) MAINTENANCE.

The importance of keeping maintenance work to a minimum on board ship need hardly be emphasised here, and normally every care is taken to minimise the likelihood of breakdowns in plant and equipment installed. Any reduction which can be effected in the number of lamp replacements during a voyage is therefore of special interest. While the average life of a general service filament lamp is rated at 1,000 hours, that of hot cathode tubes may exceed 5,000 hours and most colours of the cold cathode type average over 15,000 hours. When fluorescent tubes are used it is practical to arrange for bulk replacement at the end of their rated life when the ship is in port rather than to let them continue until failures occur, probably at sea.

Bulk tube replacement is particularly suitable with cold cathode lighting as several years may elapse before the tubes require replacing. It has been found from experience that the replacement may be arranged to coincide conveniently with redecoration work.

(d) EFFECT ON AIR CONDITIONING.

It is well known that light sources add heat to an interior which results in a rise in room temperature or an increased load on the cooling plant. Any saving which can be obtained in this direction cannot be neglected when the comfort of passengers is considered, especially on ships which sail in tropical climates. The heat from fluorescent tube lighting is considerably less than that from filament lamps for the same amount of light delivered.

For situations where coloured light sources are desirable, such as in ballrooms, an even greater reduction in heating effect is possible.

The colour media needed for producing coloured light from filament lamps reduce the overall efficiency, resulting in high current consumption and greater heat dissipation than occurs with coloured fluorescent tubes which need no such filters (Table 1).

COMPARISON BETWEEN HOT AND COLD CATHODE TUBES.

Numerous references to the operation of hot cathode and cold cathode tubes have appeared elsewhere, but this article would not be complete without referring briefly to the salient features of each type.[1, 2] Both forms of light source produce visible light mainly from a coating of fluorescent powders on the inner wall of the tube. These powders are activated by ultraviolet radiation from the mercury or neon discharge and their function is to emit visible light, the spectral composition of which can be controlled by the choice of fluorescent powders.

There are three basic differences between hot and cold cathode tubes, and these can be summarised under the following:

(a) Electrode construction and starting requirements.
(b) Tube dimensions.
(c) Range of colours.

(a) ELECTRODE CONSTRUCTION AND STARTING REQUIREMENTS.

The cold cathode electrode is of robust construction and usually consists of a hollow cylinder of unactivated nickel or iron. Under normal conditions it operates at a temperature not exceeding 200 degs. C. Cold cathode tubes are generally operated from a high-voltage leakage reactance transformer.

TABLE 1.

APPROXIMATE EFFICIENCIES OF SOME COLOURED LAMPS—LUMENS/WATT.

	RED	GREEN	BLUE
40 watt colour sprayed G.L.S. lamp	0·5	1·6	0·2
80 watt hot cathode fluorescent tube ...	3.5	40	11
Cold cathode fluorescent tube standard 9 ft. 0 in. length	13.5	32	9

NOTE.—The above efficiencies are average throughout life.

By contrast, hot cathode tubes have filamentary tungsten electrodes coated with alkaline earth oxides which normally operate at a temperature close to 1,000 degs. C. When used with suitable ballasts they can be operated directly from ordinary supply voltages.

(*b*) TUBE DIMENSIONS.

Cold cathode tubes for marine work are invariably shaped and dimensioned to suit the individual requirements of lighting features and, having a small diameter (20 mm.) they can be shaped in manufacture to suit particular needs. While the average length of these tubes is between 8 and 9 ft., they are also made in shorter or longer lengths, but their shape must be such that they can be encompassed by a rectangle 9 ft. 6 in. by 2 ft. 9 in. Short tubes are less efficient than long tubes and are used only when the situation demands.

Hot cathode tubes are made in standard sizes consisting of $1\frac{1}{2}$, 2, 3, 4, 5, and 8 ft. straight lengths. A circular tube with a diameter of 16 in. is also available. With the exception of the $1\frac{1}{2}$ ft. and 3 ft. tubes which are 1 in. diameter, the other straight tubes mentioned have a diameter of $1\frac{1}{2}$ in.

(*c*) RANGE OF COLOURS.

There is a wide range of colours available with the cold cathode tube as previously described in this Journal.[3] While many of these can be used singly, it is common practice for ship lighting to employ a combination of gold and ivory tubes which provides a quality of light harmonising well with filament lamp lighting when used in the same room or in nearby areas (fig. 2).

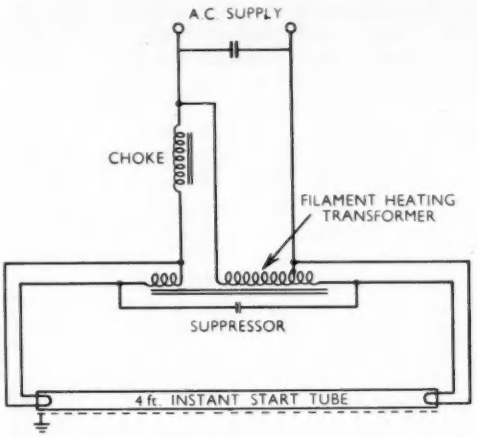

Fig. 4.—Circuit diagram for composite ballast unit shown in fig. 3.

Satisfactory results have been obtained from hot cathode tubes by using the warmer tones of white, but in some instances a better effect has been produced by lightly tinting the reflecting surfaces or diffusing media.

CONTROL GEAR.

All fluorescent tubes have to be controlled by current limiting devices which may comprise chokes, transformers or resistance ballasts. The design and characteristics of these components have a major influence on the performance and life of the tubes.

The usual supply system available in British ships is at present 220 volts D.C. While D.C. is not suitable for cold cathode equipment, methods of operating hot cathode tubes from this supply exist, but they involve a considerable loss in efficiency and it is more usual to install plant for converting to alternating current. Factors which have influenced this trend can be summarised as follows:

(*a*) A ballast resistance is necessary for each hot cathode tube used on D.C. This will dissipate in heat an additional wattage which is almost equal to the rating of the tube.

Fig. 3.—Composite ballast unit for a 4 ft. 40 watt tube in contrast comparison with choke, starter switch and capacitor.

(*b*) A means has to be provided for reversing periodically the polarity of the supply to overcome the darkening caused by the drift of mercury vapour towards the cathode, particularly in the longer tubes.

(*c*) Instant start D.C. circuits are more involved than those required for A.C. operation and may be unreliable with the longer tubes.

A description of this has already been given[4] and when planning lighting installations it is usually necessary to make provision for the accommodation of one set of gear for each hot cathode tube (fig. 4). The composite unit illustrated is frequently preferred because it is compact, avoids the use of a starter switch and simplifies wiring and fixing arrangements. It is convenient to arrange for the control gear to be housed in the lighting fitting, and while this is often possible, there is no objection to remote mounting, where preferred.

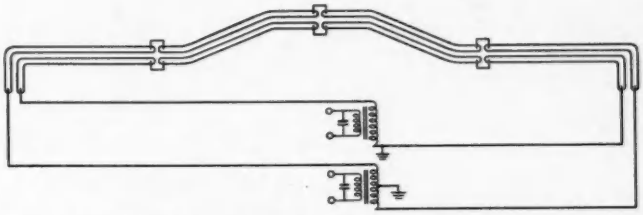

Fig. 5.—Typical cold cathode circuit showing gold and ivory tubes, each colour being connected to a separate transformer.

The difficulty of obtaining independent control of voltage and frequency with rotary inverters has caused them to be less popular and, except for very small installations, the preference is usually for a motor alternator set.

After allowing for the losses in the converting equipment, the overall efficiency of a fluorescent lighting system on alternating current is greater than that of an equivalent D.C. system.

Hot Cathode Control Gear.

Typical auxiliary gear for use with hot cathode tubes is shown in fig. 3.

One of the overriding factors in control gear design for marine installations for service in the tropics is the provision of an adequate margin between the temperature of the windings under the highest ambient conditions and the upper temperature limit for the insulation and filling.

The temperature rise of the winding is due to the power loss in the gear and this is dependent on the design and shape of the unit. The components shown in fig. 3 have been developed

TABLE 2.

DETAILS OF MARINE TYPE TRANSFORMERS AND CAPACITORS.

Transformer Type	* Tube footage/transformer		Overall Size (in.)	Approx. Weight (lbs.)	Value of p.f. Capacitor (mfd)	Size of Capacitor (in.)	Approx. Weight (lbs.)
	IVORY	GOLD	L W H			L W H	
1·8/120	13	—	$11\frac{1}{8}\times4\frac{3}{4}\times7\frac{3}{8}$	16	$12\frac{1}{2}$	$4\times2\frac{1}{4}\times5\frac{7}{8}$	$3\frac{1}{2}$
2·2/120	17	—	$11\frac{1}{8}\times4\frac{3}{4}\times7\frac{3}{8}$	18	$12\frac{1}{2}$	$4\times2\frac{1}{4}\times5\frac{7}{8}$	3
5/120	34	—	$13\frac{1}{2}\times6\frac{3}{4}\times8\frac{3}{4}$	45	30	$4\frac{1}{2}\times3\times6\frac{7}{8}$	$4\frac{3}{4}$
2·6/60	13	8	$11\times5\times5\frac{9}{16}$	12	$12\frac{1}{2}$	$4\times2\frac{1}{4}\times5\frac{7}{8}$	$3\frac{1}{2}$
7/60	42	25	$14\times6\frac{3}{4}\times8$	34	25	$4\frac{1}{2}\times3\times6\frac{7}{8}$	$4\frac{3}{4}$
10/60	76	42	$14\frac{1}{2}\times7\frac{3}{4}\times8$	40	30	$4\frac{1}{2}\times3\times6\frac{7}{8}$	$4\frac{3}{4}$

* These figures are approximate only and depend on tube lengths; the first three transformers are for tubes operating at 120 mA and the remainder for those operating at 60 mA.

to have low iron and copper losses and at the same time meet the requirement of fittings designers.

Cold Cathode Gear.

A feature of cold cathode circuits is that several tubes are usually operated from one high voltage transformer and such transformers can be conveniently centralised in a few positions. In order to comply with the regulations and specifications mentioned later, it is necessary to use metal-sheathed ozone-proofed cable in the high-voltage circuit. The transformers, which are contained in sheet steel tanks and fitted with suitable glands to receive this type of cable, should be sited so that high-voltage cable lengths are kept as short as possible. Approximately 30 ft. of twin tubing comprising gold and ivory can be operated from two transformers as shown in fig. 5.

The windings of these transformers are designed to withstand indefinitely the overload current produced if the secondary is short-circuited and the maximum average temperature rise under such conditions does not exceed 70 degs. C. Details of various transformers for different tube lengths are given in Table 2.

Power Factor Correction.

Capacitors are normally installed in both hot cathode and cold cathode installations to correct the power factor to not less than 0·85. When convenient, bulk power factor correction can be arranged and the number of capacitors reduced. In such instances the terminal boxes are designed for conduit or cable entry (fig. 6).

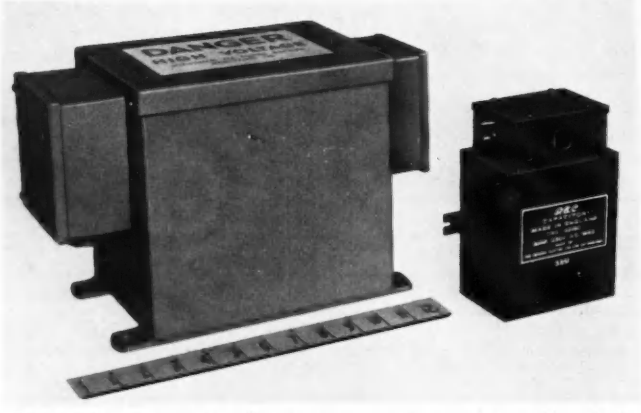

Fig. 6.—Marine-type transformer and capacitor used in cold cathode installations.

REGULATIONS APPLICABLE TO LIGHTING INSTALLATIONS.

Under the Merchant Shipping (Construction) Rules, 1952, all electrical equipment must conform to the relevant provisions of the Regulations for the Electrical Equipment of Ships, issued by the Institution of Electrical Engineers. Reference is made below to some of the essential points of these regulations and also to the appropriate rules as published by Lloyds Register of Shipping and British Standard Specifications.[5, 6, 7]

The terminal voltage of alternators should be automatically maintained at within 2½ per cent of normal voltage and the size of conductors feeding a lighting load must be such that the voltage drop in them does not exceed 6 per cent of the busbar voltage. The maximum voltage drop at the terminals of a lighting fitting would, therefore, be 8½ per cent of nominal voltage, which is within the design tolerance allowed for on fluorescent lighting equipment described in this article.

The fittings should be designed so that dust and moisture cannot readily accumulate on the insulation or live parts. Insulated conductors must be protected against damage from rough projections and sharp angles, and outlets should be well rounded or bushed; also attachments should be vibration and shakeproof. Lighting fittings, control gear and cables for fluorescent tubes used in ocean-going ships are to be suitable for marine use under tropical conditions.

Transformer windings are restricted to an average temperature rise of 50 degs. C. for class A insulation above a standard reference ambient temperature of 45 degs. C. They should be of drip-proof construction and placed in well-ventilated, easily accessible compartments clear of all ignitable materials. The windings should be treated to resist moisture and sea air and should not be open to mechanical injury. Transformers are also to be subjected to short-circuit and high-voltage tests at the manufacturer's works in accordance with the above-mentioned regulations. A further requirement is that the secondary open-circuit voltage shall not exceed 5,000 volts to earth.

For cold cathode installations the secondary or high-

Fig. 7.—Cold cathode cornice designed to follow the shape of the dance floor in the first-class lounge of the Oslofjord.

voltage circuit is to be isolated from the supply system and permanently earthed at the transformer, the core is also to be earthed. In addition all live metal parts are to be enclosed in an earthed metal case which is to be sealed against access by unauthorised persons.

Plans showing layout and circuit details for every cold cathode installation, are to be submitted to Lloyds for approval.

THE APPLICATION OF FLUORESCENT LIGHTING

When considering the application of fluorescent tubes for public room lighting it is essential to give due thought to the quality as well as to quantity of the light. In addition to being functional, the lighting should assist in enhancing the architectural and decorative treament and at the same time contribute to creating the right atmosphere in the particular location (fig. 7).

The appearance of food, clothing and complexions is one of the criteria by which the success of a fluorescent lighting installation will be judged. Experience has shown that the colder shades of the white fluorescent tubes do not always meet with general approval for public room lighting especially when lighting in adjoining rooms is

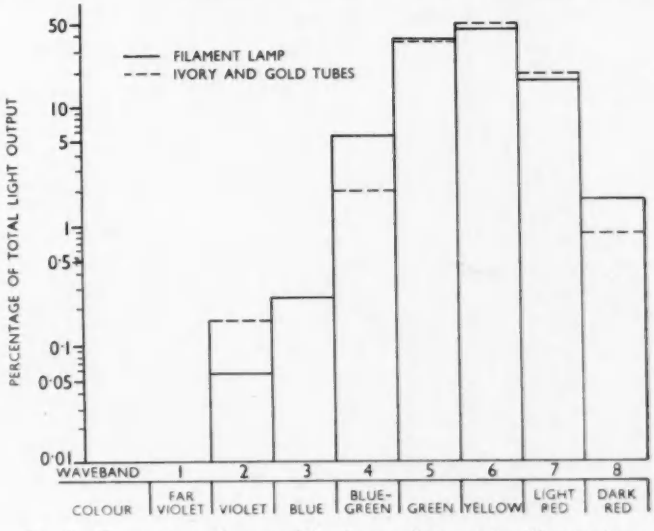

Fig. 8.—Comparison of spectral luminance diagrams for filament lamp and combination of ivory and gold tubing.

by filament lamps. So long as filament lamps continue to be used in cabins and galleys there will no doubt be a demand for a fluorescent light source with somewhat similar colour-rendering properties. Care has therefore to be exercised when selecting the colour of fluorescent tubes to be used for public rooms and while this need not necessarily simulate very closely the well-known colour produced by filament lamps, experience shows that any wide departure therefrom may not be acceptable (fig. 8).

In many rooms full advantage can be taken of the efficient colours available with fluorescent tubes. For instance, a warmer quality of light is often preferred in cocktail bars and ballrooms. This can be obtained by selecting suitable tube current values in a two-colour cold cathode scheme to adjust the proportion of red in the light.

Typical of the scope offered by employing coloured light sources is the arrangement in the dining saloon of a well-known liner. The general illumination is provided from gold and ivory fluorescent tubes in glazed cornices and this is used when breakfast and lunch are served. An entirely different atmosphere is created for dinner, however, by bathing the saloon in rich gold light from the gold tubes alone. Supplementary local lighting is then provided by individual table lamps which assist in enhancing the general attractiveness of the room (fig. 9).

It is often desirable to introduce a more intimate atmosphere than that afforded by fluorescent lighting alone. This may be achieved by adding carefully selected wall brackets, a graceful floor standard or a neat table lamp here or there (fig. 10). While not contributing much to the overall illumination these may be relied upon to produce the right effect.

Higher intensities of illumination have become usual to-day and values of between 12 and 15 lumens/sq. ft. are common in public rooms and foyers. Apart from the necessity of avoiding direct glare from light sources there is also the possibility that these higher illuminations

Fig. 9.—Separate control of two-colour cornice lighting and table lamps provides a variety of lighting effects in this dining saloon.

Fig. 10.—Well-chosen wall brackets improve the effect from an indirect lighting system.

may introduce uncomfortable brightness contrasts of patterns on walls, ceiling or furnishings. The appearance of these contrasts is governed by the light distribution from the light sources employed and the reflection factors, textures and positions of the various surfaces in an interior. Although this particular problem in public room lighting does not merit the same attention that may be necessary in more functional surroundings, such as in offices, it is suggested that care should always be taken to avoid undesirable brightness contrast in large adjacent areas.

INDIRECT LIGHTING.

The demand for decorative lighting fittings will undoubtedly continue, but it is nevertheless felt that the cornice has an important function to perform in the lighting of public rooms in ships (fig. 11).

The space available for recessing lighting equipment into the ceilings is often limited because of numerous obstructions normally found between the ceiling and the deckhead. Not the least of these is trunking, which is an essential feature of the ventilation system, and often the positioning of cornices and lighting fittings is dictated by the layout of this trunking. Co-operation between all parties concerned when the interior planning is being considered would enable compromises to be made so that neither the ventilation nor the lighting would be impaired.

When cornice lighting is employed, the best indirect lighting effects will be obtained when the distance between ceiling level and cornice is at its greatest. Quite often the low ceiling height in ships will restrict this distance, and in such cases the lighting effect can be improved by introducing a feature such as a small step where the cove joins the ceiling, to break up the gradation of brightness (fig. 13).

When the height of the deckhead permits, excellent results may be obtained by using a carefully designed cove which springs from the back of the cornice to the ceiling over a distance of four feet or more. Fig. 14 is an example of a dining saloon where the coving has been lighted evenly by providing a suitable contour.

Fig. 11.—Hot cathode tubes carefully positioned in a curved cornice provide a good indirect lighting system in a writing room in the City of Port Elizabeth.

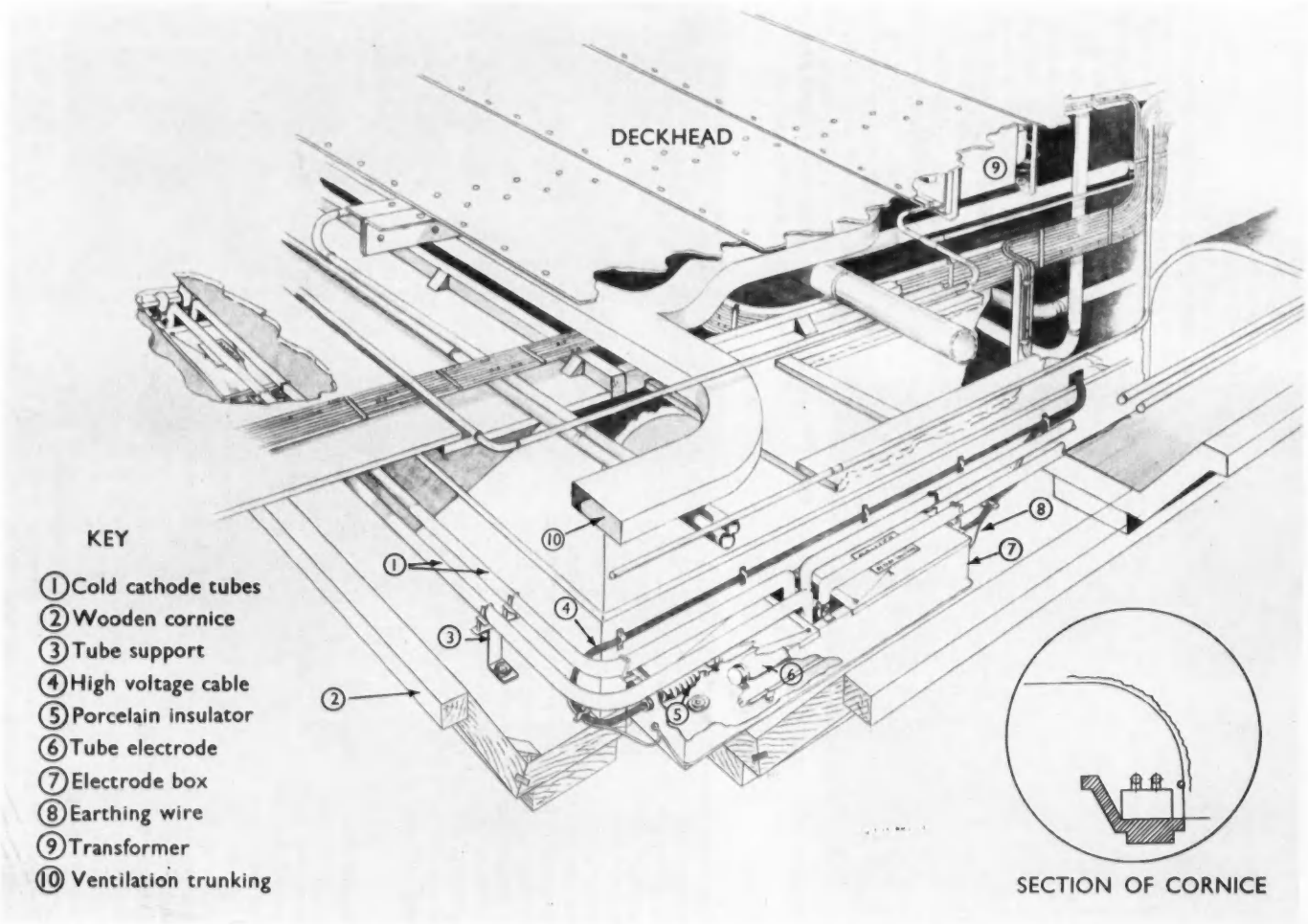

Fig. 12.—An artist's impression illustrating the technique in cold cathode cornice lighting.

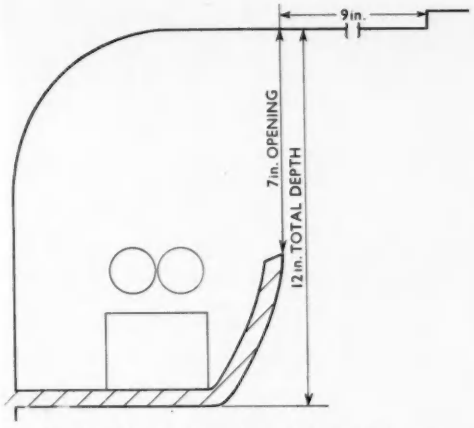

Fig. 13.—The introduction of a step in the ceiling line improves the appearance of an indirect lighting system when dimensions of cove are limited.

(*a*) Description of Typical Cornice Using Cold Cathode Tubes.

A section of a cornice similar to those frequently used in marine installations is illustrated in fig. 12. Although the space available between the cornice and ceiling is only 10 in. this is adequate for tube replacement. As can be seen from the drawing the control gear is recessed into the ceiling void in close proximity to the tubes. A continuous line of light is obtained by turning the electrodes parallel under the luminous part of the tube and butting adjacent tubes as close as half an inch to each other. The method of enclosing the electrodes and supporting the tubes on non-tracking insulators is indicated, together with labelling arrangements. The equipment is supported on resilient mountings as a precaution against vibration, and the high-voltage connection is clamped securely to the electrode caps. In accordance with the requirements of British Standard No. 559 the cable ends terminate in porcelain insulators which are sealed with compound against moisture and ozone penetration. Electrode boxes for twin tubing are approximately 3 in. high by 5 in. wide, while smaller boxes are used for single tube intallations. The H.V. cable between one electrode and the transformer can be seen secured to the back of the cornice.

When the control gear is accommodated in the ceiling void, it is desirable to arrange for access and this presents little difficulty provided it is discussed with the Decorative Architect during the stages of planning. Control gear can also be housed, when convenient, in suitable lockers in adjacent bulkheads.

(*b*) Cornice Treatment Using Hot Cathode Tubes.

A method which has been used to obtain a continuous line of light in cornices was to overlap batten type fittings; this necessitated a cornice wide enough to contain two gear channels. In order to reduce the size of the cornice a special fitting has been designed which has the additional advantage of producing a more even lighting effect (fig. 15). The back plates can be fixed in line along the cornice at the correct intervals and the offset position of the lamps will automatically ensure overlapping, as shown in fig. 16.

Through-wiring is provided in the backplate between terminal blocks fitted at each end, which enables adjacent fittings to be easily linked together and connected to one final sub-circuit.

Fig. 14.—The sweeping line of this ceiling contributes to the success of the indirect lighting in the Oslofjord.

The system makes for ease of maintenance as a faulty unit can be detached quickly, simply by unplugging and unlocking the two quick-release fasteners. The fitting illustrated is also suitable for instant start gear.

Semi-Indirect Lighting.

Very satisfactory results can also be achieved from cornices which are partly or completely glazed to provide a semi-indirect lighting system; many such installations exist in which the underside only is glazed. These include one recently completed in the library of a ship where fluorescent tubes have been fitted over the front of the bookshelves to provide illumination on the ceiling and downward illumination on to the books.

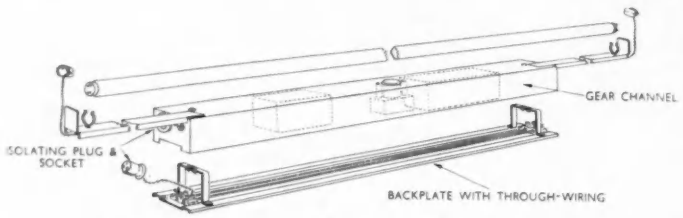

Fig. 15.—Exploded view of hot cathode fitting for cornice lighting showing tube in offset position for overlapping.

It is not surprising that glazed cornices are being used extensively for ship lighting in view of the very low ceiling heights so often available (fig. 17). Not only is it necessary to select the glassware with care and obtain satisfactory diffusion of the light source but particular attention should also be paid to the finer details of design if the best results are to be assured. These include (*a*) the framework of the fitting must be held rigidly during normal service and be capable of being opened easily when required for tube replacement, (*b*) the use of material for glazing frames which will not tarnish or discolour under the effects of a salt-laden atmosphere and (*c*) positioning of glazing bars to coincide with tube ends (fig. 18).

Ceiling Fittings Embodying Fluorescent Tubes.

The majority of fluorescent tubes used in lighting fittings are straight and this has influenced the design to the extent that these fittings are usually predominantly rectangular in shape. There is ample scope, however, for a wide range of designs and that shown in fig. 19 is typical of those employing straight cold cathode tubes. The fitting can be designed to have only a small projection below the ceiling, when there is sufficient space above the ceiling for accommodation of control gear.

The recent increase in the popularity of fittings louvred on the underside has led to a demand for similar units on board ship. When the louvres are of metal or opaque material they will control the spread of light to a comparatively small area and this may result in patchy lighting unless the spacing of the fittings is carefully arranged. Louvres made of a plastic material having a reasonably high transmission factor will, on the other hand, decrease this effect and a further improvement can be obtained by arranging for the fittings to have translucent sides to enable the ceiling and the upper part of bulkheads to be lighted.

Dimming of Fluorescent Tubes.

A requirement in most ships is that the lighting in certain spaces, such as the cinema and ballroom, must be capable of being dimmed (fig. 20). Formerly fluorescent tubes have been dimmed by a number of different systems and the results were reasonably satisfactory. An electronic dimming system has recently been developed by the G.E.C. and it will in the future be possible for fluorescent tubes installed on board ship to be controlled and dimmed smoothly to a degree hitherto unknown. The system,

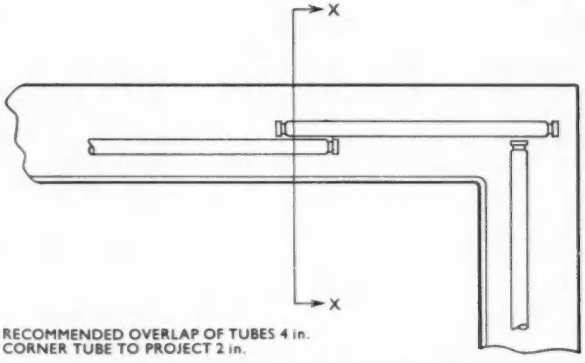

Fig. 16.—One method of using hot cathode tubes in a cornice to obtain a continuous line of light. Section XX is shown in fig. 13.

Fig. 17.—Glazed cornices are used with advantage in the foyer of the Ocean Monarch, where the ceiling height is only 7 ft.

which will apply both to hot cathode and cold cathode tubes, will be of great value in ballrooms, where full advantage can be taken of the efficient coloured light sources provided by fluorescent tubes.

The following are the principal advantages this system offers when compared with other methods of dimming fluorescent tubes:

(*a*) Simplicity of wiring and circuits.
(*b*) Compact unit.
(*c*) Wide dimming range with all colours, both hot cathode and cold cathode.
(*d*) Low power loss.
(*e*) Reliability.

A typical unit will control up to 350 ft. of cold cathode tubing or thirty-two 5 ft. hot cathode tubes. A proportion of filament lamp lighting, if desired, may also be included in the total load to be dimmed by one dimmer.

CONCLUSION.

No attempt has been made in this article to examine the economic aspects of alternative lighting systems. While the initial cost of a cold cathode installation may be higher than that of a hot cathode installation, this may be offset by the longer tube life and fewer replacements required. Capital costs and running costs vary between wide limits for different applications of the same type of tube and it is felt that any general conclusions on this point might be misleading. Also, it is difficult to overestimate the value of a well-planned and well-executed lighting installation on board ship in terms of passenger comfort and goodwill.

It would be unwise to predict the type of tube and circuit arrangements which are likely to prove most popular in the future. Hot cathode and cold

Fig. 18.—Glazed cornice designed to suit the character of this dining saloon.

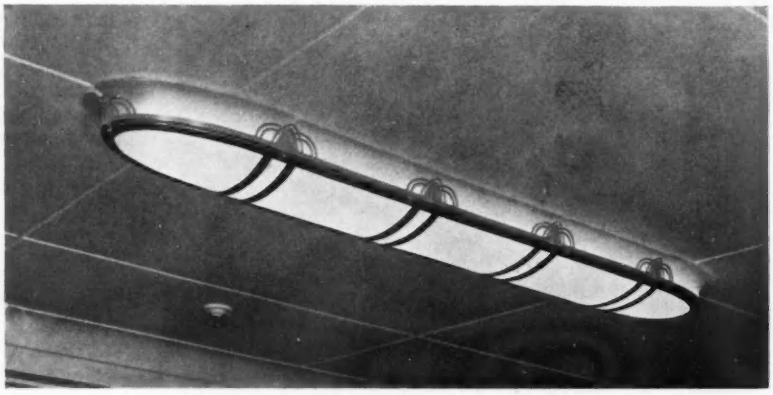

Fig. 19.—Decorative cold cathode ceiling fitting in the Queen of Bermuda, with transformers remotely positioned.

cathode tubes each have points in their favour and the best lighting results will be achieved only when due consideration is given to the requirements of each individual lighting problem. A number of ships in service at the present time is fitted with one or other type of tube and there seems little doubt that fluorescent lighting will find increasing use in this important field.

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Fig. 20.—Dimmer-controlled fluorescent lighting in the ballroom of the Oranje.

Electric Locomotives for the South African Railways

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Traction Department, Witton.

INTRODUCTION.

DURING the last quarter of a century the South African Railways have electrified large sections of their system at 3,000 volts D.C., and are now engaged on the electrification of the main line between Capetown and Beaufort West, a distance of some 330 miles (fig. 1). The 3,000 volt D.C. system has again been adopted, both on account of the excellent service it has given and for the sake of standardisation. When the work has been completed both passenger and goods trains will be operated by electric locomotives. A contract for forty locomotives for this service was placed by the South African Railways with the North British Locomotive Co. Ltd., The General Electric Company of England being the contractors for the electrical equipment.

Known as the 4E class, these locomotives are among the largest yet built for 3 ft. 6 in. gauge, and are now being delivered (fig. 2).

The requirements as called for in the specification covered both performance and train timings, the limiting feature as regards loading being the 20 miles of 1 in 66 grade between Hex River and New Kleinstraat. On down grades the speed had to be kept at the figures quoted in Table 1 by regenerative braking only. Furthermore, the locomotives had to be capable of starting a 1,070-ton goods train on a 1 in 66 grade or a 610-ton passenger train on a 1 in 50 grade. For convenience the requirements

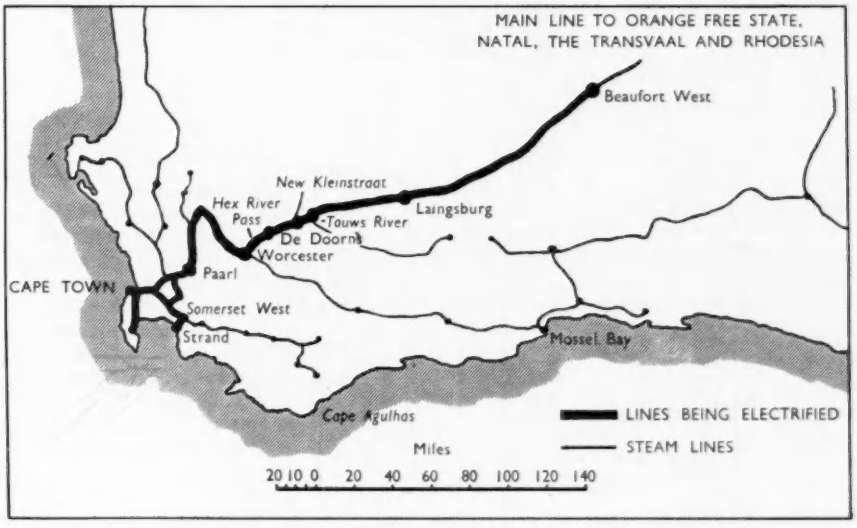


Fig. 1.—Map of the Capetown-Beaufort West Line.

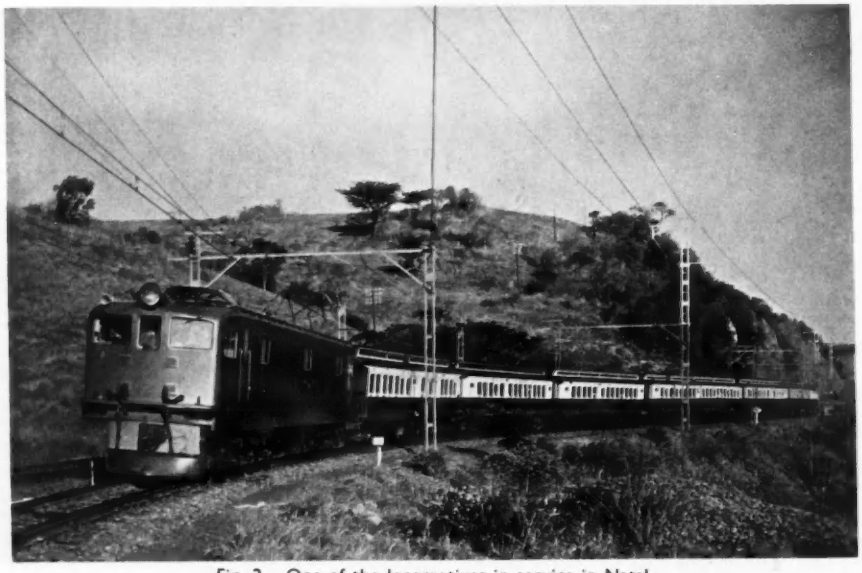


Fig. 2.—One of the locomotives in service in Natal.

specified are given below in Tables 1 and 2.

To meet the foregoing requirements, a 3,030 h.p. six-motor locomotive, with three motor combinations and a moderate range of field control in each combination was provided. The performance curves of the locomotive as built are shown in figs. 3 and 4.

At the time the contract was placed, it was intended to construct a new line with a maximum gradient of 1 in 66 between De Doorns and New Kleinstraat. This would have eliminated the considerable stretches of 1 in 40 grade on the existing line; a profile of this section is shown in fig. 5. Subsequently it was decided not to proceed with this project and therefore two locomotives will have to be used to take the heaviest trains over this section of the route.

The first locomotives delivered were put into service between Durban and Volksrust in Natal.

TABLE 1.

PERFORMANCE REQUIREMENTS.

Type of Train	Gradient	Max. Speed Required m.p.h.
610 ton passenger	Level	56·5
	1 in 100 up	38
	1 in 66 up	34
	1 in 50 up	31·5
	1 in 66 down	40 to 55
	1 in 50 down	30 to 45
900 ton goods	1 in 66 up	25·5 and 30
1070 ton goods	Level	35
	1 in 66 up	24·5
	1 in 66 down	25 to 40

GENERAL DESCRIPTION.

The locomotive is of the double bogie type, each bogie being provided with three driving axles and a leading pony axle. The main frame

TABLE 2.

TRAIN TIMINGS.

Train	Running Time, hr. min.	Av. Speed, m.p.h.	Max. Speed, m.p.h.
610 ton passenger —Capetown to Beaufort West ..	7 43	43	55
610 ton passenger —Beaufort West to Capetown ..	7 25	44·7	55
900 ton goods— Capetown to Beaufort West ..	11 28	29	35
1,070 ton goods— Beaufort West to Capetown ..	11 12	29·6	35

and bogies are of heavy all-welded construction. The general arrangement is shown in fig. 6, and the principal dimensions and other particulars are tabulated below :

Gauge	3 ft. 6 in.
Length over couplers	71 ft. 8 in.
Bogie wheelbase	22 ft. 5 in.
Total wheelbase	60 ft. 4 in.
Wheel diameter (driving)	4 ft. 3 in.
Wheel diameter (pony)	2 ft. 6 in.
Total weight in working order	155 tons
Adhesive weight	129 tons
Tractive effort (at 25 per cent adhesion)	72,000 lb.

Full field continuous rating	32,100 lb. tractive effort at 28·5 m.p.h.
Weak field continuous rating	25,500 lb. tractive effort at 37·6 m.p.h.
Full field one hour rating	41,700 lb. tractive effort at 26·7 m.p.h.
Weak field one hour rating	33,600 lb. tractive effort at 34·2 m.p.h.
Maximum service speed	60 m.p.h.
Reduction gear ratio	21/75.
Minimum radius of curve	275 ft.

The locomotive body is symmetrically arranged with a driving cab at each end. Behind each cab is a machinery compartment, and in the centre portion of the locomotive is situated the enclosed high-tension compartment.

The driver's cab (fig. 7) houses all the master control equipment for the power, auxiliary and braking equipment, together with certain switches and lighting circuit breakers which are preferably under the driver's control. Directly in front of the driver, and below the window, is a panel on which the various gauges, meters and certain indicator lamps are mounted. Behind the driver are the main control switch, which is key-operated, and a number of circuit breakers for the lighting circuits. The battery is situated in two cubicles arranged on either side of the front doorway.

The machinery compartments contain the various auxiliary machines and much of the L.T. control equipment associated with them. Fig. 8 shows one of the L.T. panels on the bulkhead with one of the machines alongside. These compartments have open corridors and contain no H.T. equipment except the actual connections and commutators of the H.T. motors which have bolted or key-operated covers with a warning notice. "Perspex" windows are fitted in the commutator covers of these machines.

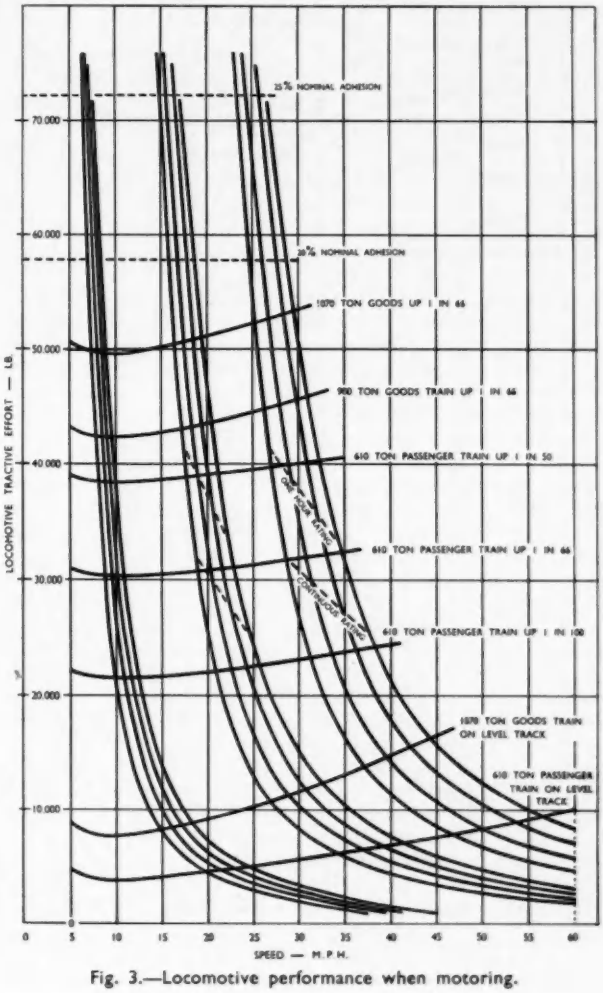


Fig. 3.—Locomotive performance when motoring.

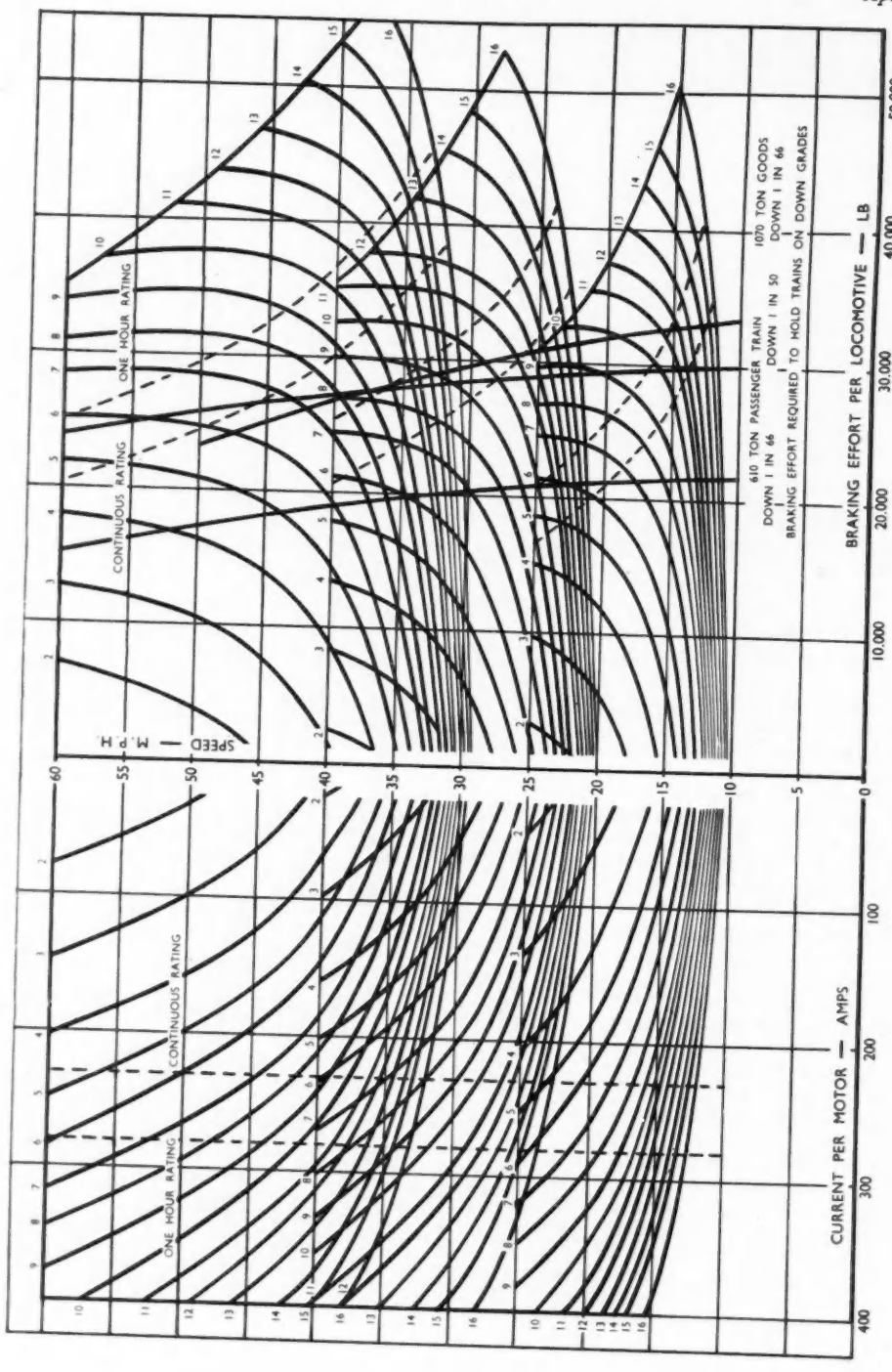

SPEED — M.P.H
CONTINUOUS RATING
ONE HOUR RATING
610 TON PASSENGER TRAIN
DOWN 1 IN 66
DOWN 1 IN 50
1070 TON GOODS
DOWN 1 IN 66
BRAKING EFFORT REQUIRED TO HOLD TRAINS ON DOWN GRADES
BRAKING EFFORT PER LOCOMOTIVE — LB
CURRENT PER MOTOR — AMPS

Fig. 4.—Locomotive performance when regenerating.

The H.T. chamber contains all the H.T. power and auxiliary control equipment such as camshaft changeover switches, main contactors and main H.T. auxiliary circuit breaker. Included in this chamber are the two resistance compartments which house all the various resistances associated with the H.T. circuits. These compartments are self-contained in order to prevent the hot air entering the apparatus section. Along one side of these three compartments runs a corridor which, with the open corridor of the machinery compartments, provides a passage from end to end of the locomotives. Entry into the H.T. apparatus compartment is possible only through an interlocked door in the corridor. The lock of this door is operated by the reverse key and consequently it cannot be opened unless the main power has been cut off. Furthermore, the operation of the primary lock lowers the pantograph and opens the auxiliary circuit breaker so that it is impossible to break current on the pantograph and burn the overhead line. Final interlocking of the door earths the supply. The resistance chambers can be entered only from the apparatus chamber so that their doors require no interlocking, but as it is essential that they should be closed when the locomotive is in operation, an indicator lamp is provided which shows a red light should either door be left open. Part of one of the frames in the H.T. compartment is shown in fig. 9. Mounted at the top are various overcurrent and protective relays, while at the bottom is a row of main contactors with the auxiliary circuit breaker fitted with an extension arc chute at the end. Fig. 10 shows one of the banks of resistances in its frame before being mounted in the locomotive.

The ventilation system of the H.T. compartment is somewhat unusual and its performance in service is proving most satisfactory. It is effected by diverting a portion of the cooling air from the ducts leading to the traction motors. This system assists materially the convection currents which cool the resistances and also maintains a slight pressure in the H.T. chamber so that any danger of ionised air collecting in that chamber is virtually eliminated. Furthermore, the dust which can enter is reduced to a negligible quantity. The whole of the cooling air for the locomotive is filtered through dry fabric type filters mounted in the side walls of the machinery compartments, the air passing through ducts to the fan inlets.

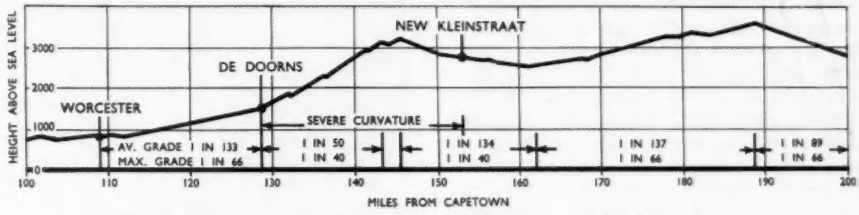


Fig. 5.—Profile of the line between De Doorns and New Kleinstraat.

ELECTRICAL SCHEME.

Power Scheme.

The power circuits are shown in schematic form in fig. 11, from which it will be seen that current is collected from the overhead line by one or other of the two pantographs, each of which is provided with an isolating switch. All the main and auxiliary power circuits are fed through a main isolator which is interlocked with the H.T. chamber door and pantograph control.

As previously mentioned, the locomotive performance demands three groupings of the six driving motors both when motoring and regenerating. These combinations are series, series-parallel and parallel and arrange for the motors to be connected in series across the line as one group of 6, two groups of 3 or 3 groups of 2 respectively.

In following the power circuits it should be noted that power contacts indicated without a circle, such as *SP*2, *P*7, or *LS*4, are pneumatically operated contactors which are opened by a spring when the air is released and are capable of breaking current. The contacts shown in rings, such as *B*1 or *B*2, are not capable of breaking current, but only of forming the circuits as required. They are opened or closed by a camshaft operated by air pistons and are arranged in two separately operated units indicated by single and double circles respectively. Each group has motoring and regenerating positions. To obtain motoring connections, both must be in " motoring " for all motor combinations. To obtain regeneration in the parallel combination both must be in " regeneration ", but for the series and series-parallel combinations only the single ringed group is in the " regeneration " position.

Contacts *A* and *V* are similarly cam-operated and serve to reverse the motor fields in order to change the direction of motion of the locomotives.

Changing from one combination of motors to another is effected by the well-known shunt transition which maintains a suitable drawbar pull during regrouping and is simple and reliable. Starting resistance is first reinserted in circuit, after which certain motors are short-circuited and disconnected from their series connection with others, followed by the required regrouping. Grouping is accomplished by means of the combination contactors *S*, *SP* and *P* while the starting resistances are cut in and out by the contactors *R*. Obviously certain grouping contactors must be associated with the starting resistances as well as with the motor circuits so that the resistances are correctly regrouped. The contactors *LS*, which also fulfil a function in motor grouping, are the main feed contactors and, in association with certain resistance contactors, serve as line switches. Upon the operation of a motor overcurrent, line overcurrent or overvoltage relay, resistance is first inserted in the circuit after which these line switches open.

In each motor combination four continuous running steps are provided by field excitation control, namely (1) full field excitation by closing of contactors *FF*; (2) field diversion by closing contactors *FA*; (3) further field diversion by closing contactors *FB*, and (4) weakest field excitation by closing contactors *FT* and opening contactors *FF*. Opening of contactors *FF* eliminates any risk of instability which might arise if a portion of the field winding were short-circuited.

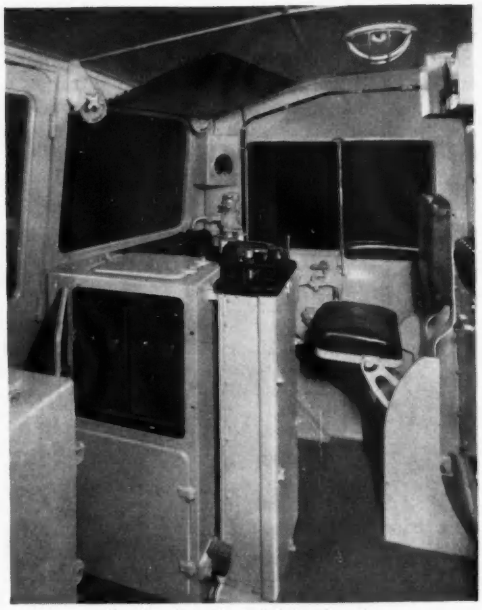


Fig. 7.—Interior of driver's cab.

When regenerating, the motor fields are separately excited by means of a variable voltage exciter *E*, the changeover from motoring to regenerating being effected by cam groups which

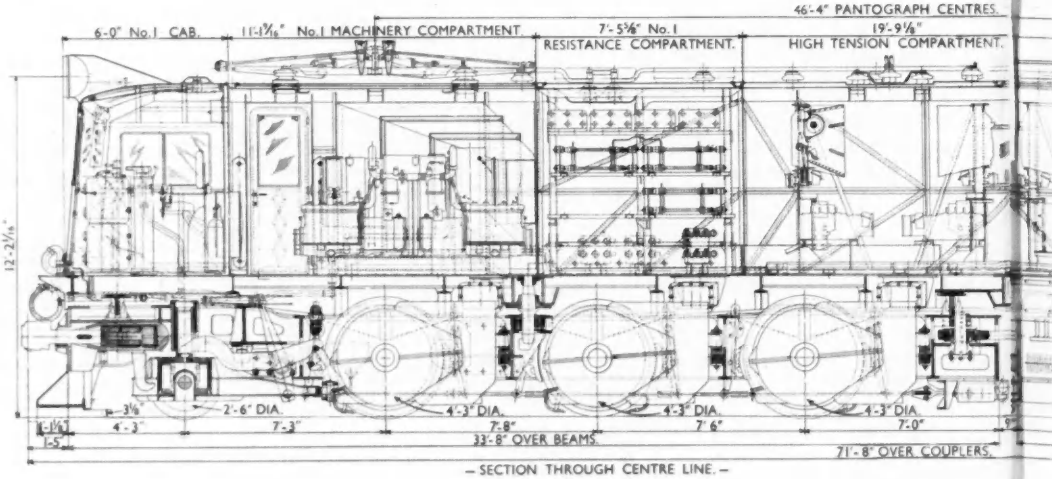


Fig. 6.—Arrangement the

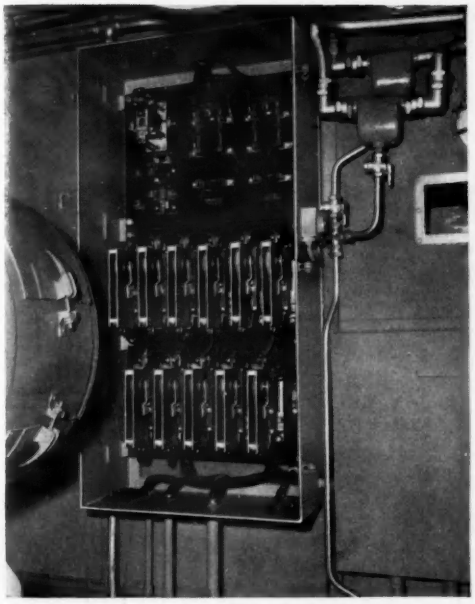


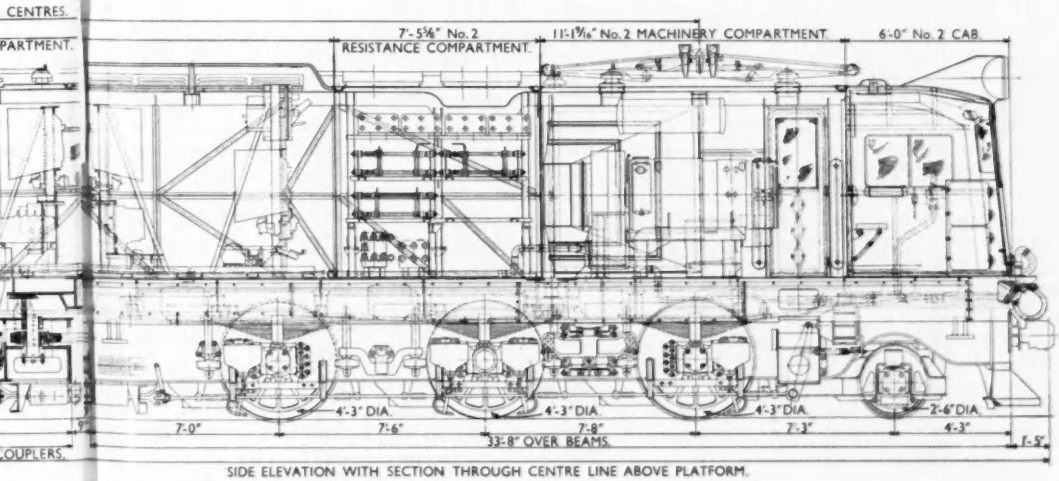
Fig. 8.—One of the L.T. control panels in the machinery compartment.

operate the contacts *B*. An inverse compound regenerative characteristic is obtained by feeding the excitation current through a stabilising resistance which also carries the main current. Thus any increase in the load current will reduce the excitation of the motor fields and ensure stability. The correct regenerative characteristic is determined by the cam groups which vary the arrangement of the stabilising resistance according to the motor combination. One cam group initiates the main changeover to regenerative connection, while the second governs the changes in the combination of the motors during regeneration. There are no closed transitions from one combination to another. A combination must be selected and, after the correct generated voltage has been obtained, the motors are connected to the line and the starting resistance gradually cut out while the central zero ammeter is observed. The system is so simple that in an emergency, regeneration can be set up without observing the instruments by carefully regulating the excitation as the starting resistance is reduced.

As lightning surges are a constant danger in South Africa, special precautions are taken to safeguard the locomotives. In addition to the conventional double spark gap on the roof, a Ferranti surge absorber, also mounted on the roof, and auxiliary spark gaps with blowouts are associated with both the power and auxiliary circuits. In addition, the insulation of all high tension equipment, including machine windings, is designed to withstand a pressure test of 10,500 volts A.C.

Control Scheme.

All the power contactors are of the electro-pneumatic type, so that the master controller



SIDE ELEVATION WITH SECTION THROUGH CENTRE LINE ABOVE PLATFORM.

rangement of the locomotive.

handles only small currents at 112 volts for operating the valves. A comprehensive system of interlocks ensures the correct sequence in all circuit changes and affords full protection in the event of failure of any component.

The master controller is provided with three handles (fig. 12). The first selects forward or reverse running as well as the various motor combinations. The second controls the cutting out of starting resistance both during motoring and regenerative braking. The final notches of this handle operate the field weakening contactors so that this feature can be used on any motoring combination. It should be noted that field weakening is not available when the motors are regenerating. The third handle sets up the regeneration connections and controls the exciter voltage. As the locomotives always have a crew of two, no deadman's features are provided.

To carry out a motor transition to a higher speed grouping, the driver first selects the next combination on the reverse and combination handle, and then proceeds to introduce starting resistance, the correct value being obtained by operating a stop on the resistance handle which is arrested in its correct position when thrown back by the driver. Transition then follows automatically and the main resistance may be cut out again to accelerate the locomotive. Mechanical interlocking of the handles prevents faulty operation. When regeneration is required the driver first selects the desired motor combination by the reverse and combination handle, after which he moves the regeneration handle from its motoring position and by notching it up slowly obtains a voltage balance with the line voltage. The motors are then connected to the line with all the starting resistance in circuit. The resistance is then cut out step by step, the driver keeping a watch on the ammeter reading. Braking is controlled by notching the regenerative handle backwards or forwards as required. Should the overcurrent or overvoltage relays operate, starting resistance sections are at once connected in the circuit, followed by further sections and finally by the opening of the line switches.

If a traction motor should fail, the three motors on either bogie may be isolated and the locomotive safely operated with a limited performance.

In order that more than one locomotive can be driven from one driver's cab, all the locomotives are provided with control train lines and couplers, sixty train lines being needed for the complete power and auxiliary control.

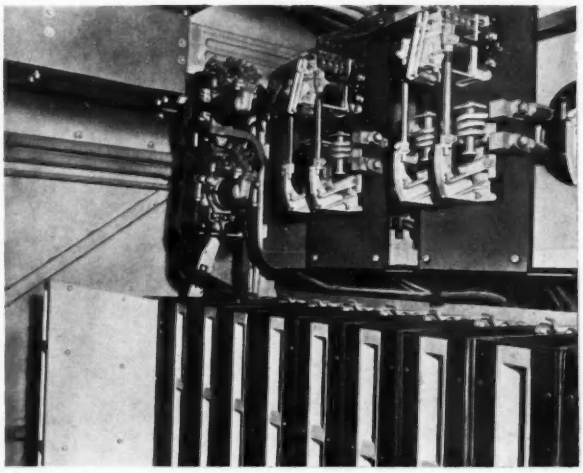


Fig. 9.—Part of one of the control frames in the H.T. compartment.

Auxiliary Scheme.

On locomotives of this size and performance there is necessarily a considerable amount of auxiliary power equipment, and its operation and control are of great importance. The 3,000 volt auxiliary equipment comprises the motors driving the exciter and L.T. generator. Protection of both machines is afforded by an auxiliary circuit breaker. This breaker can also be set and tripped by hand and functions as a means of starting and stopping the machines. Each set is provided with automatic resistance starting equipment and may be isolated from the supply in the event of failures. No regenerative braking is possible if the exciter set is isolated, but this set can be used to provide some L.T. supplies in an emergency.

The motor generator set supplies current for battery charging, for the fields of the exciter set, for the two exhauster motors, compressor motor, lighting, control circuits and heaters, its voltage being controlled by a regulator in the generator field.

Master contacts in the driver's brake valve provide automatic speed control of the exhauster motors, while the compressor motor is automatically started and stopped by the air pressure

in the main reservoirs. All these machines are provided with automatic starting equipment to limit the starting current peak, and with over-current relays. Lighting and control circuits are protected by circuit breakers, no fuses being used.

The battery floats across the L.T. generator and is automatically kept charged. Its normal function is to supply the lighting and control circuits if the L.T. generator is not running, but its capacity is such that it can be used in an emergency for running the exhausters for a reasonable period.

MECHANICAL PARTS.

Main Frame and Bogies.

The main frame consists of two heavy, fabricated, longitudinal members of " I " section with the greatest depth at the pivot points. It is braced throughout with fabricated stretchers at the bogie pivot points and with " T " sections, both longitudinally and transversely, at other points. The headstocks are of fabricated " I " section. Steel plates, welded together, form a continuous platform over the main frame, trap doors giving access to the traction motor brush gear.

The bogies (fig. 13) are fabricated from heavy section steel plates, adequately stiffened in the lateral direction by welded steel stretchers. The couplers are mounted on the bogie, the traction and braking loads being transmitted through a pin-jointed link between the bogies. The link pins are mounted in spherical bearings which allow full relative movement in all three planes.

The axlebox horns are of cast steel, secured to the frame with fitted bolts, and faced with manganese steel liners. Manganese steel facings are also provided on the Timken axleboxes, no lubricant being applied between the axleboxes and horn guides.

In addition to the drag link between the bogies for transmitting tractive effort, the inner ends of the bogies are connected by a transverse form of linkage which is under a special form of spring control. This permits the bogies to oscillate independently of one another while the spring control tends to keep these oscillations in phase.

This linkage is between the bogies only and is in no way associated with the locomotive frame. Such an arrangement is of great benefit when entering a curve since the leading bogie will tend to turn more than the trailing bogie and is permitted to do so in a restrained manner by the action of the spring linkage. Since normally the two bogies react one against the other within the limits of the spring control, there is a beneficial effect on flange wear on curves.

Control of the side movement of the pony trucks relative to the bogie frames is such that it provides a constant resistance to such movement and tends to return the trucks to the centre. It consists of two steel rockers working in top and bottom bearings and through these rockers the load is transferred from the bogie to the pony truck. The arrangement is somewhat similar

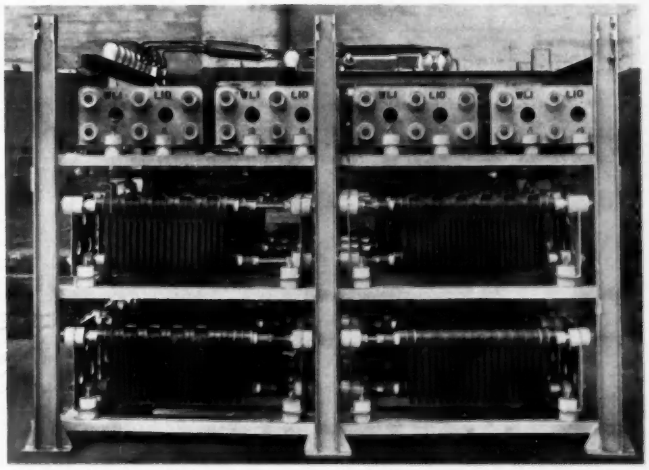
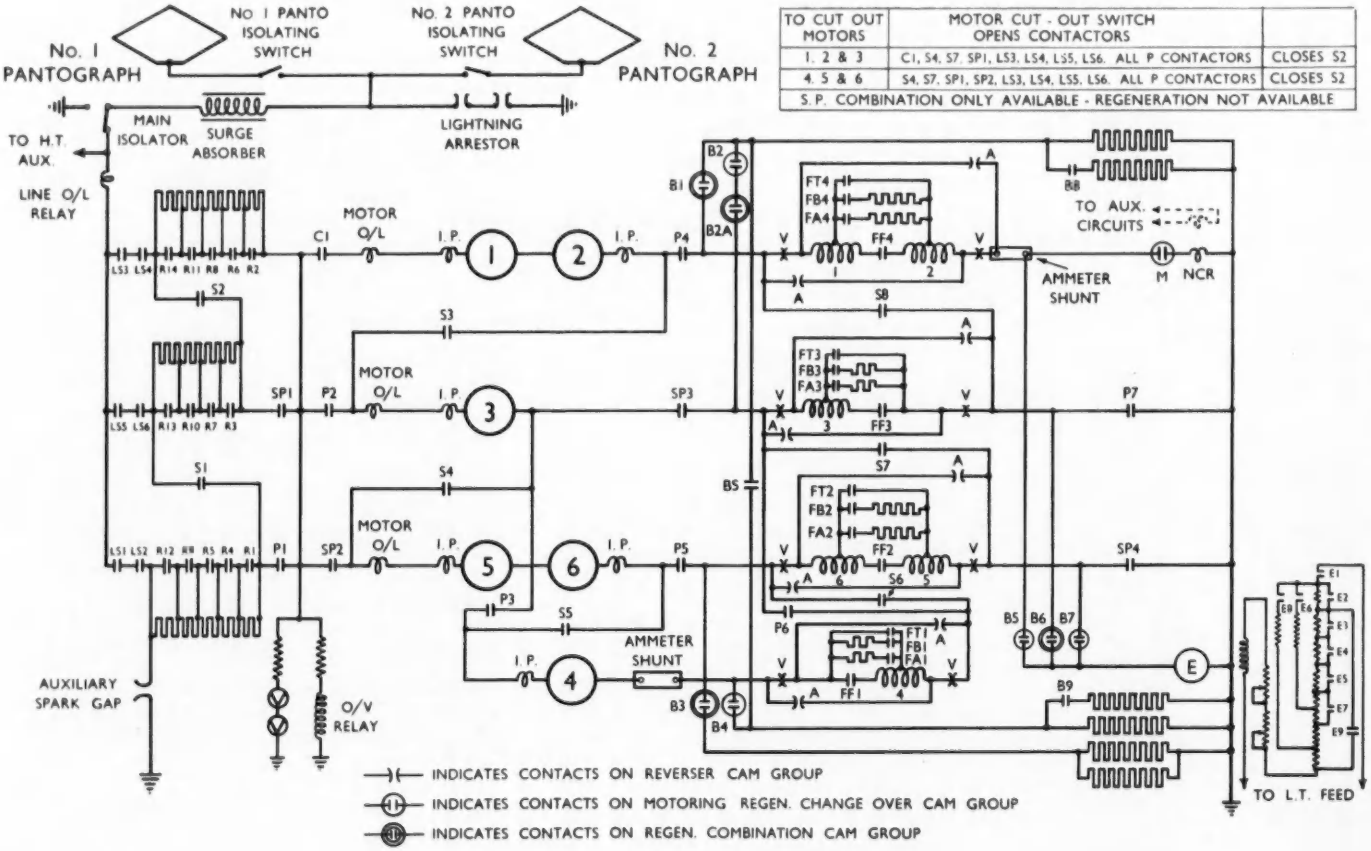


Fig. 10.—One of the resistance banks before being mounted in the locomotive.



TO CUT OUT MOTORS	MOTOR CUT - OUT SWITCH OPENS CONTACTORS	
1. 2 & 3	C1, S4, S7, SP1, LS3, LS4, LS5, LS6. ALL P CONTACTORS	CLOSES S2
4. 5 & 6	S4, S7, SP1, SP2, LS3, LS4, LS5, LS6. ALL P CONTACTORS	CLOSES S2
S.P. COMBINATION ONLY AVAILABLE - REGENERATION NOT AVAILABLE		

Fig. 11.—Main power schematic diagram.

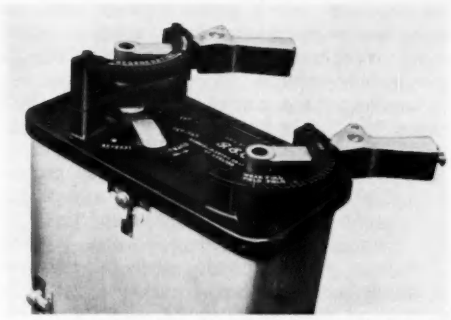


Fig. 12.—Arrangement of the three handles of the master controller.

to that of gravity link control on a bolster type bogie but is inverted, the rockers acting as struts rather than hangers. The wearing surfaces of the rockers and bearings are case hardened and the bottom bearing surface is grease-lubricated.

The driving axlebox springs are of the laminated type having solid spring links with auxiliary rubber damping springs. On each bogie the pony truck, which has coil springs, and the leading driving axle, are side- and cross-equalised as a group. The intermediate and trailing driving axles are side-equalised but not cross-equalised. Thus the bogie frame is suspended on the three point suspension principle. The body is carried on each bogie by means of four spring loaded bearers. These bearers also provide limited friction to damp out oscillation of the bogies, should it arise.

The bogie pivot pins are attached to the underside of the main frame, and fit into a manganese bronze centre bush on each bogie. The bush bodies are spherical and are held in case-hardened steel half-bearings, which are adjustable for wear. Lubrication is by oil fed from oil boxes in the machinery compartment at each end of the locomotive. Flat rubber damping pads on either side of the centre bush of each bogie lessen side thrust shock from the rails. The bush at No. 1 end bogie has no end movement, but that at No. 2 end bogie is permitted a movement of 1 inch in the longitudinal plane, so that the bogies can run freely round a curve of the minimum radius.

Superstructure.

The cabs, body side, corridor and partition walls are built of steel sheet. They are of unit construction and are welded to the main frame. A corridor on one side of the body runs between No. 1 and No. 2 machinery compartments. The roof is removable over the following compartments: machinery compartment No. 1 end, which houses the motor generator set and vacuum exhauster, resistance compartment, high tension compartment, resistance compartment and machinery compartment No. 2 end which houses the motor exciter set and air compressor. Trap doors in each compartment give access to the traction motors.

Doors are situated on each side of the body in No. 1 and No. 2 machinery compartments, while a sliding door gives access from the corridor to the high-tension compartment. Access to the cabs is by a door in the end wall of each machinery compartment.

The cab accommodation provides for a driver

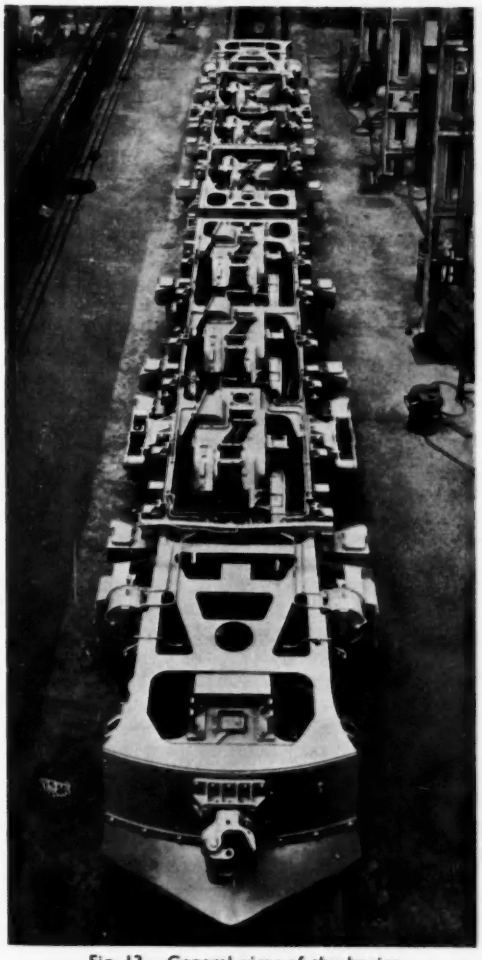


Fig. 13.—General view of the bogies.

and assistant, heating units being built-in under their respective desks. The driver sits on the right-hand side of the cab, between the master controller and the vacuum and straight air brake valves, with all his controls within easy reach. The hand brake is at the assistant driver's position. Since the locomotives are arranged to work in multiple with others of the same type, doors in the cabs allow the assistant driver to pass from one locomotive to another for inspection purposes.

Fig. 14.—One of the traction motors.

An Elliott speedometer is mounted in each cab, and a mileage counter, regenerative mileage counter and speed recorder in No. 2 end cab. This recorder carries a chart which is driven by an 8-day clockwork motor, the chart lasting thirty days on a 1-inch per hour travel. An axle-driven generator with make-and-break contacts operates the speedometer, speed recorder and mileage counter. An air-operated Typhon horn at each end of the locomotive is operated by a pedal valve in the driver's footstool or by a push button at the side of his seat. Windscreen wipers, operated by air pressure, are provided for the driver and assistant.

Brake Equipment.

The brake equipment was supplied by the Westinghouse Brake and Signal Company, Ltd., and provides for a system of straight air brakes on the locomotive with means for operating vacuum brakes on the train. The vacuum system acts automatically in the event of a breakaway, and applies the air brakes on the locomotive through a vacuum/air proportional valve, provided the driver's air brake handle is not in the release position. Regenerative braking is also provided and is interconnected with the mechanical brakes so that in the event of failure during regeneration the vacuum brakes are automatically applied.

The compressed air supply is obtained from a two-cylinder, motor-driven air compressor which maintains the pressure in the main reservoir for operating the locomotive brakes, sanding, horn, control and pantograph equipment. The compressor is controlled by a master governor which starts the compressor when the pressure falls below 80 lb./sq. in. and cuts out when a pressure of 90 lb./sq. in. is reached. With multiple operation, the governors on the two locomotives are interconnected so that the compressors are synchronised. The main reservoirs are also connected together through hose couplings, so that in the event of failure of one compressor the other will charge up the reservoirs on both locomotives.

Two vacuum exhausters of the four-cylinder "Westex" type are provided to operate the brakes on the train. These exhausters normally run at 600 r.p.m. or at 1,200 r.p.m. to obtain quick release of the brakes. The snifting valves limit the maximum vacuum obtainable to 18 in. Hg, while a check valve prevents a back flow of air into the train pipe when the exhausters are shut down. An automatically controlled valve blanks off the exhauster from the train pipe whenever brakes are applied.

The brake rigging is fully compensated with brake blocks on each side of the twelve driving wheels, each bogie having two brake-operating cylinders. The hand brake in each cab operates the brakes on the respective bogies. A pneumatic automatic slack adjuster progressively takes up the movement of the brake rigging when it exceeds a predetermined amount due to wear of the brake blocks and tyres. It ensures that the brakes will be fully applied without allowing the stroke of the brake cylinder piston to exceed 5 in. When the travel is greater than 5 in., the piston uncovers a port in the brake cylinder wall through which air is admitted to the slack adjuster. On releasing the brake, the slack adjuster piston is moved back by a spring and carries with it the pawl which turns the rachet wheel round the adjusting screw. This shortens the total length of the slack adjuster, and hence the effective length of the pull rods, thereby preventing excessive travel of the brake piston.

SANDING EQUIPMENT.

Air sanding equipment is provided and is operated by electro-pneumatic valves which are controlled from a button switch in the driver's footstool. Each bogie is provided with eight sanding boxes : a pair forward of the leading power axle, a pair forward of the middle power axle, a pair at the rear of the middle axle and a pair at the rear of the trailing axle. Thus, for either direction of motion of the locomotive, eight sanding boxes are operative and eight wheels directly sanded. Control of sanding appropriate to the direction of travel is selected by a connection between the button switch and the master controller reverser.

MACHINES.

TRACTION MOTORS.

Each axle-hung traction motor (fig. 14) is of the 4-pole series type arranged for forced-ventilation and weighs 5¼ tons complete with gears and gear case.

The motor characteristic curves are shown in fig. 15, and the ratings, which exceed those of any motor previously built for operation on a 3 ft. 6 in. gauge, are tabulated below :

Motor Ratings at 1,450 V in accordance with British Standard No. 173/1941.

Continuous rating, full field
232 amp., 420 h.p. 672 r.p.m.

Continuous rating, weak field
242 amp., 440 h.p. 888 r.p.m.

One-hour rating, full field
282 amp., 505 h.p. 630 r.p.m.

One-hour rating, weak field
290 amp., 525 h.p. 807 r.p.m.

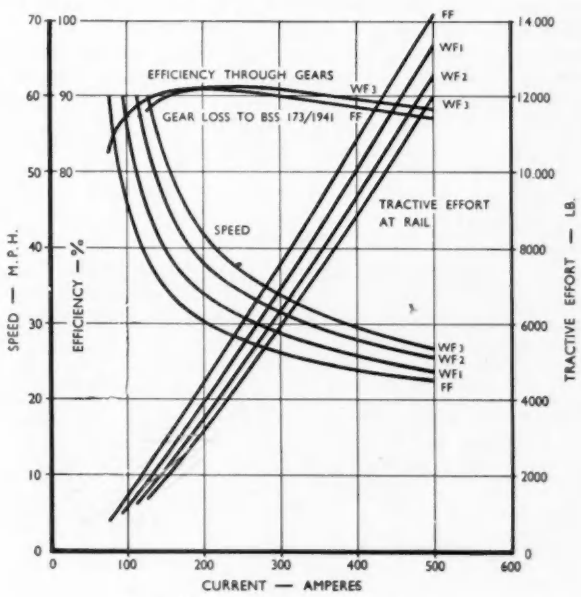


Fig. 15.—Motor characteristic curve.

As the motors have to carry heavy currents at high speed during regeneration, special attention has been given to design features which assist commutation, and the success which has attended these measures may be judged from the performance of the motor on test when commutation proved completely satisfactory at 1½ times the continuous rated current with the motor running on 1,600 volts at a speed equivalent to 60 m.p.h.

Although space in the bogie is strictly limited, there were no corresponding weight restrictions and this simplified the provision of the extremely sturdy construction demanded by the more than usually severe service conditions.

Each motor is suspended from the bogie transom by a nose cast on the frame and resting in a cradle which is carried on rubber pads. Manganese steel wearing surfaces are provided on the nose and the cradle.

The lateral forces imposed on the track have been considerably reduced by allowing the motor a limited amount of transverse movement relative to the axle under the control of rubber springs between the motor and the bogie frame. These springs, which can be clearly seen in fig. 13 are prestressed so that the motor is normally held in a central position on the axle by the action of opposing springs. Thrust faces are provided on the suspension bearings but act only as stops to prevent excessive axial movement of the motor.

The suspension bearings are clamped in position by a single cast-steel axle cap located by large spigots and secured by bolts which, following G.E.C. standard practice, are screwed into nuts and not into tapped holes in the motor frame. Lubrication of the suspension bearings is effected by oil syphoned through wool packing from a large reservoir in the axle cap.

The armature is carried in grease-lubricated roller bearings and can be removed from the motor frame without opening up the bearing assemblies so that there is no fear of dirt entering the housings during this operation.

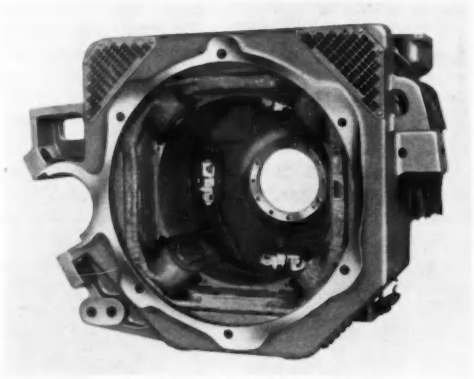


Fig. 16.—Motor field system.

Hard mica wraps moulded on to the coils serve to insulate the slot portions of the armature windings, and during manufacture the windings and insulation are consolidated while hot into a solid mass, all interstices being filled with an insulating cement. On the completion of this process, the slot wedges are fitted and the end winding bands applied.

Locomotive motor armature failures have, in the past, resulted from melting of the solder in the commutator joints when heavy trains were started on severe gradients. For this reason a solder is used which does not become plastic until a temperature of 236 degs. C. is reached as compared with 183 degs. C. for a tin-lead solder.

The complete field system is shown in fig. 16. The coils are formed from copper strip with interturn insulation of treated asbestos, the main insulation consisting of cambric-backed mica with an outer taping of asbestos. Finally the coils are impregnated with synthetic resin varnish which is then polymerised and thus produces coils of great strength with excellent insulating and heat dissipating properties.

Studs of fatigue resistant alloy steel fix the interpoles to the motor frame. They are securely anchored in the pole body, and are surrounded by non-magnetic bushes where they pass through the motor frame so that they cannot form a magnetic path across the brass liner which is interposed between the pole and the frame. This construction (Patent Application No. 14907/51), coupled with careful grading of the interpole gap to give the best field form, has proved most effective in ensuring correct interpole strength over a wide current range and thus greatly assists commutation. Furthermore, it avoids the use of non-magnetic studs which are not only weaker, but also reduce appreciably the magnetic section of the interpole body.

Each brush box (fig. 17) is carried on an insulated bar, clamped at each end to the motor frame. Provision is made for radial movement to allow for commutator wear, but the brush boxes are accurately located circumferentially by dowels. They can be removed as complete units without disturbing any connections.

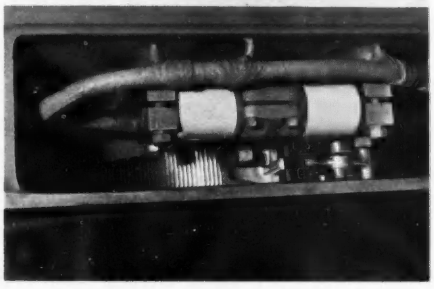


Fig. 17.—Traction motor brushgear.

GEARING.

The single spur reduction gearing through which the motor drives the axle was manufactured by Alfred Wiseman, Ltd., the tooth profile complying with British Standard No. 235/1951. The medium carbon steel pinion is shrunk on to a

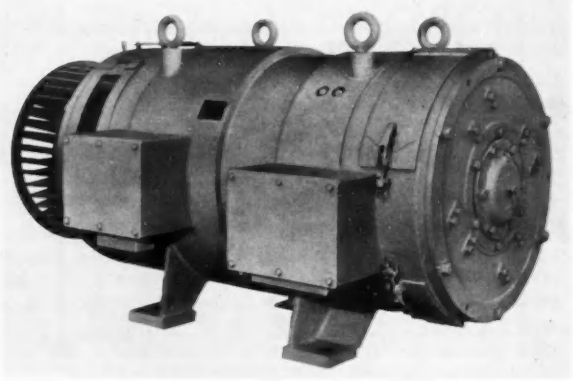


Fig. 18.—22 kW motor generator set and blower.

tapered seating on the armature shaft, no keys being used. The teeth are taper-ground to ensure even distribution of the load over the gear face. The resilient gear wheel comprises a carbon chrome toothed rim mounted on a cast-steel hub, the drive being transmitted from the rim to the hub through Silentbloc rubber units. A large degree of resilience has been obtained by using two Silentblocs in series, one being mounted in the rim and the other in the hub with a steel pin forming the connecting link.

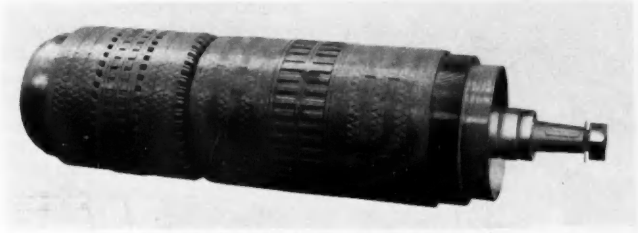


Fig. 19.—22 kW motor generator armature.

The gears are enclosed in a fabricated gear case supported from the motor frame. As gears of this design require a more fluid lubricant than do solid gears, maximum oil-tightness is obtained by using flange joints in conjunction with a sealing compound, the flanges being bolted together wherever possible. Seals on the axle and motor frame are made with a graphite impregnated woven material.

Motor Exciter and Motor Generator Sets.

Each locomotive is provided with a 43 kW motor exciter set which energises the motor fields when regenerative braking is used, and a 22 kW motor-generator set (fig. 18) for supplying the L.T. power and lighting circuits. Incorporated in each set is a blower which supplies the cooling air for three of the traction motors.

The sets are of the two-bearing type with a ball bearing at the generator end and a roller bearing at the motor end. They follow standard traction practice, both the motor and generator armatures being mounted on a common shaft (fig. 19) with the field systems housed in a single fabricated frame. The rotating parts are accurately balanced dynamically so that the machines run very smoothly.

The driving motors operate on the 3,000 volt supply and are of the two-pole type which is preferred for its increased reliability as compared with four-pole machines. A small series resistance is connected in the armature circuit. The exciter and L.T. generator are of four-pole construction with lap and wave windings respectively. The equaliser connections of the exciter form part of the commutator assembly and are entirely separate from the main winding.

In the case of the 22 kW set, the blower takes a sufficient proportion of the total load to permit the use of a series-wound driving motor, but for the 43 kW exciter set the driving motor is provided with an additional motor field fed from the L.T. supply in order to limit the speed range between maximum and no generator load.

Glass-covered wire is used for all high-tension field and armature windings, while copper strip is used for all other windings, the forms of insulation being generally similar to those already described for the traction motors.

It is essential that the output characteristics of the exciter set be maintained within close

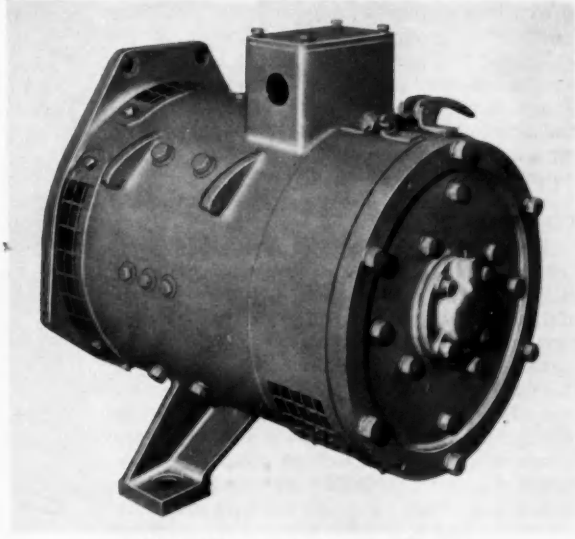


Fig. 20.—Driving motor for the exhauster.

limits, and because of the low voltage at which the exciter operates this can be achieved only if the brush characteristics are also consistently maintained. The brush grade must, therefore, be such that the brush and commutator surfaces are unaffected by the long periods of no-load running which occur in service. For this duty a dual grade split brush was chosen and is giving satisfactory results.

Forced ventilation of both the exciter set and L.T. motor generator is obtained by air bled from the ducting to the traction motors. The air enters the sets midway along the frame and passes outwards to discharge through openings at either end so that both the generators and the driving motors are supplied with cool air.

Exhauster Motors.

The Westinghouse type 4V110 exhausters are driven by 110 volt series motors (fig. 20). The armature is mounted on an extension of the exhauster crankshaft, while the motor frame is spigoted to the crankcase. The motor develops 3 h.p. at 600 r.p.m. or 6 h.p. at 1,200 r.p.m., the speed being varied by means of a field tap; the motor is continuously rated at both outputs.

CONTROL APPARATUS.

The main power, auxiliary power and control schemes for a locomotive of this class demand a large amount of very specially developed control and switching equipment. Many isolating switches and changeover switches are required to meet emergency conditions in the event of failure of a component. Some are on the 3,000 volt circuits, some on the 112 volt circuits, while others may be associated with both. Hence special consideration has been given to insulation. All 3,000 volt circuits are adequately insulated to earth. The low-tension circuits are not earthed as it can be shown that a higher degree of safety results from the non-earthing of the low-tension side when the high-tension side is earthed. This is because in a locomotive there may be a very high resistance to earth if sand or dirt has blown onto the track. Furthermore, in order to ensure a high degree of safety, there is always the equivalent of an earthed barrier between the low-tension and high-tension circuits when they are associated with one piece of apparatus.

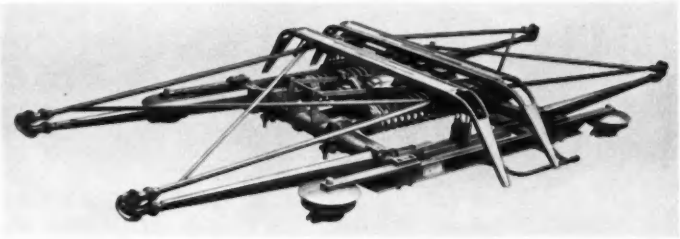


Fig. 21.—General view of the pantograph.

Space does not permit a full description of all the interesting and unusual forms of smaller

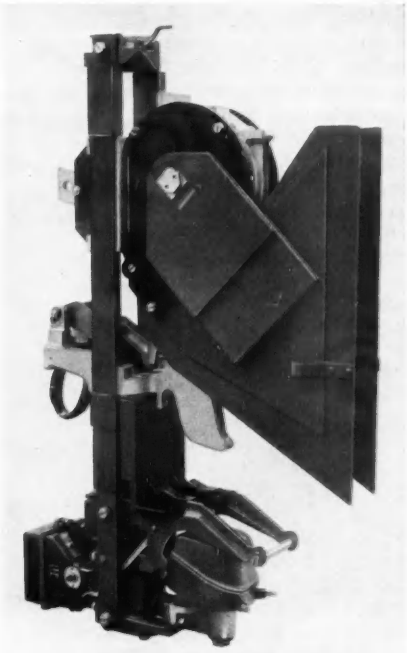


Fig. 22.—3,000 volt, 300 amp. main contactor.

witches used and it is proposed to confine these notes to the essential components of a major nature.

PANTOGRAPH.

The pantograph (fig. 21) is of the lightweight heavy duty type. It is maintained in its up position by two springs operating on cranks on the two tubular cross members. It is brought down by an overriding spring which more than overcomes the upward springs and is contained in the centre cylinder. When air is admitted to this cylinder, the down-spring is fully compressed and the up-springs completely free to raise the pantograph and permit it to follow the line. Upon releasing the air, the down-spring predominates and the pantograph is held in its down position. The main feature in its design is the arrangement of the pans. One of the major difficulties is to devise a scheme whereby the drag reaction of the pan due to friction of the overhead line is neutralised as far as ever possible. In this design, each pan is carried on two radius arms, so arranged that those of the one pan cross those of the other pan, thereby allowing the radius arms to be of unusual length. This construction neutralises to a very large degree the additional pressure of the leading pan and the reduced pressure of the trailing pan which has been a source of trouble in the past. So far as the question of neutralising the reaction of the pan itself is concerned, i.e. the increased pressure on the leading strip and the reduced pressure on the trailing strip, this is brought to a satisfactory value by locating the pivotal point of the pan to its carrier as high as possible. The pans are so arranged that they can only move up and down on their springing parallel to the general plane of the pantograph. Ball bearings are introduced to a very large degree in order to reduce friction and the pantograph characteristic shows very little variation in pressure throughout its stroke.

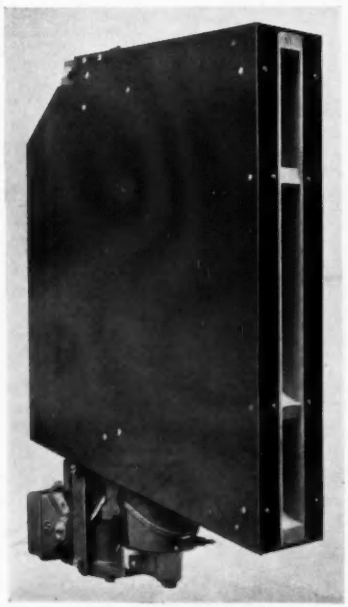


Fig. 23.—3,000 volt, 300 amp. main contactor with arc chute in position.

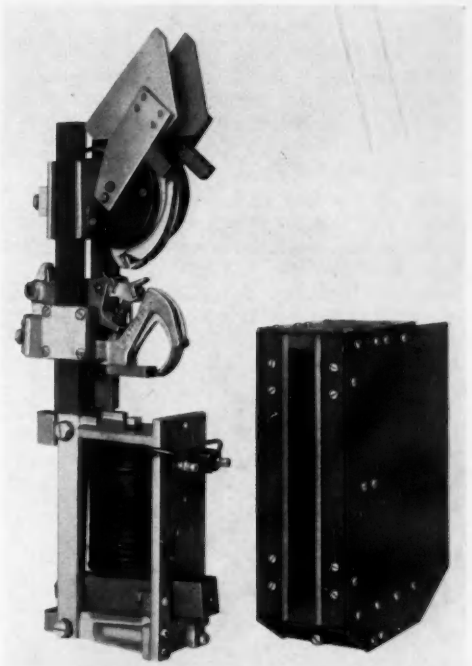


Fig. 24.—One of the 3,000 volt auxiliary contactors.

3,000 VOLT, 300 AMP. MAIN CONTACTOR.

The main 3,000 volt, 300 amp. contactor is shown in fig. 22. It is of the electro-pneumatic type and is built up on two side bars with a fixing cross member at the top and the air cylinder at the bottom. The top contacts with the blowout and magnetic blowout plates are carried from the bars near the top and the movable contact carried from the bars below. The electro-pneumatic operating valve is arranged in the

front at the bottom with the totally enclosed silver-contact interlocks behind. Fig. 23 shows the contactor with its arc chutes mounted. These contactors have been subjected to most exhaustive power tests with currents exceeding 8,000 amps. and voltages up to 4,000.

3,000 volt Auxiliary Contactor.

A small 3,000 volt auxiliary contactor (fig. 24) is built on somewhat similar lines, but is operated by a solenoid of the clapper type.

Main Changeover Cam Group.

One of the main changeover cam groups is shown in fig. 25. An insulated bar construction carries the fixed and moving contacts and a centre shaft carries the bakelite cams which operate the contacts. The contacts are provided with the usual knuckle arrangement on the moving arm and are spring-closed and cam-opened. This is considered far more reliable and safer than cam-closing and spring-opening. Towards the left may be seen the dust-tight case containing the butt interlock contacts. It should be noted that all the connections are made outside this chamber. The contacts are similar to those on the master controller which are also operated by bakelite cams.

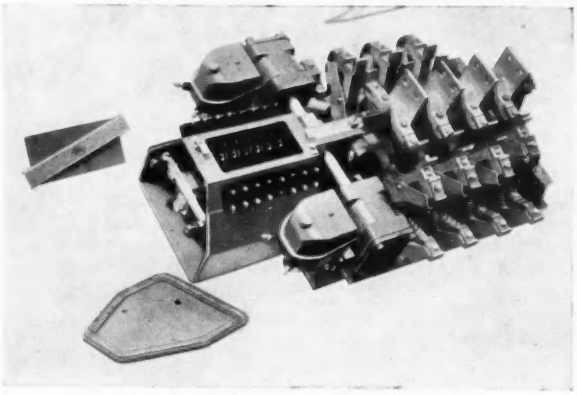


Fig. 25.—Main changeover cam group.

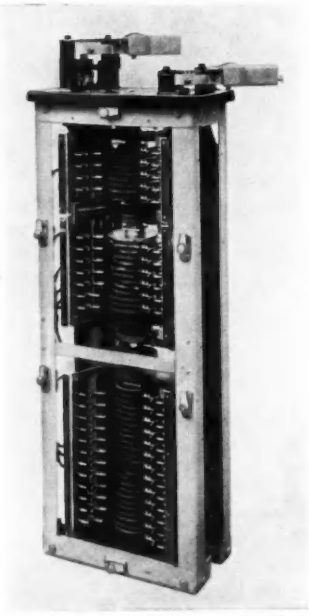


Fig. 26.—Master controller with cover removed.

Master Controller.

The master controller with the covers off is seen in fig. 26 which provides a clear view of all the bakelite cams and the silver butt contacts which open or close the requisite circuits. It will be noted that the three drums are on the same centre: the top being the reverse and combination drum, the middle the regenerative control drum, and the bottom the main resistance and weak field drum.

Main Resistance Unit.

The main resistance units on these locomotives are subject to extremely heavy duty due to the grades, the loads hauled and the fact that working very close to the limits of adhesion is unavoidable. Very careful consideration was given to these resistances and after extensive investigation, it was felt that for this particular locomotive the only solution was, in most cases, to use a heavy cast-iron type of resistance. The cast iron used is of a special corrosion-resisting type which also has a degree of flexibility. The resistance units or grids are carried on micanite-insulated bars and are insulated where necessary with micanite washers. They are also insulated from the end frames which are themselves insulated from the main frames. Consequently triple insulation is provided. On each carrying bar a take-up spring is provided, in order to avoid the trouble that used to be experienced due to a certain amount of slack developing and causing burning of the contact surfaces. Field weakening and regenerative stabilising resistances are of the strip type.

TECHNICAL LITERATURE

A DIGEST OF RECENT BOOKS, ARTICLES AND PAPERS, BY MEMBERS OF THE G.E.C. AND ITS ASSOCIATED COMPANIES

THERMIONIC VACUUM TUBES.

W. H. Aldous (Research Laboratories) and Sir Edward Appleton.

Methuen & Co., Ltd.

This is a completely re-written and up-to-date version of Sir Edward Appleton's classic monograph.

The earlier chapters cover the design of diodes, triodes and multi-electrode valves, showing how the theory of their internal action gives rise to their measured characteristics. This is followed by discussion of the use of these characteristics to give amplification, oscillation, frequency changing, etc., the emphasis throughout being to show the similarities between valve types rather than emphasise their differences.

About one-sixth of the book is devoted to the use of valves at high frequencies, covering both triode modifications and the newer types such as klystrons and magnetrons.

IDENTIFICATION BY X-RAY DIFFRACTION OF CRYSTALLINE INCLUSIONS IN GLASS (512).*

By H. P. Rooksby (Research Laboratories).

The Analyst, Vol. 77, No. 920, pp. 759-762, November, 1952.

An account is given of the use of the X-ray diffraction method for determining the nature of crystalline inclusions in glass.

The constitution of "stones" occurring in glass articles provides evidence about origin, so that identification by X-rays is of considerable practical importance. A common source is refractory material from the walls or roof of the melting tank or pot; silicates such as nephelite, $Na_20.Al_20_3.2Si0_2$, or leucite $K_20.Al_20_3.2Si0_2$, are found in lime-soda and potash-lead glasses, and reveal chemical reaction to have taken place between refractory and glass. Entirely different compounds are found if the inclusion has arisen from devitrification or from undissolved batch.

The investigation of opal glasses by X-rays is also discussed. The presence of the fluorides of calcium and sodium in one class was established some twenty-five years ago. More recent examination of opal glasses containing lead and arsenic shows the opacifying material to be a lead arsenate with apatite-like crystal structure, of comparison $3Pb_3(As0_4)_2.Pb0$. If phosphorus is substituted for arsenic, the opacifying medium is the isomorphous phosphate. These substances are structurally similar to minerals such as mimetite and pyromorphite.

SECONDARY ELECTRON EMISSION FROM BARIUM OXIDE (513).*

By J. Woods and D. A. Wright (Research Staff of the M.-O. Valve Company at the G.E.C. Research Laboratories, Wembley, England).

British Journal of Applied Physics, Vol. 3, pp. 323-326, October, 1952.

The effect of temperature on the secondary emission of barium oxide is found to be small between room temperature and 600 degs. C. With evaporated layers, the D.C. value of the secondary emission coefficient at a bombarding energy of 240 volts falls from near 3 at 10^{-6} cm. to about 2 at 10^{-4} cm. The pulsed value is about twice as large as the D.C. for the thinner films. For sprayed coatings the coefficient is near 2, and is the same D.C. as pulsed. During operation, there are rather complex short time effects, but over a long period the coefficient falls, and decomposition of the oxide occurs.

A TEN-CHANNEL PULSE CODE TELEMETERING SYSTEM (516).*

By A. J. Bayliss (Research Laboratories).

Electronic Engineering, November, 1952.

A telemetering system is described by which ten meter readings may be transmitted over a single voice-frequency telegraph channel in four seconds. Quantities to be transmitted are converted into a seven-digit binary code by means of a relay set working in conjunction with a special coder balance device. An electronic distributor employing cold cathode switching tubes scans the coded quantities and transmits the codes in the form of 20 millisecond pulses. At the receiver another electronic distributor routes the incoming code groups to the appropriate relay decoders, where the value is displayed on a moving coil meter.

A STUDY OF THE LIVES OF POTS USED IN MAKING GLASS (520).

By Joan Keen (Research Laboratories) and Denys Page (Southern Electricity Board).

Applied Statistics, Vol. 1, No. 3.

The glasses needed for special lamp bulbs are melted in small quantities in clay pots. When a pot breaks it must be removed from a very hot multi-pot furnace without changing the temperature. Charts are kept to help to ensure that pot lives are as long and as uniform as possible to reduce such replacements to a minimum. Since lives are affected simultaneously by the pot-maker, the furnace and its gas-firing, the pot type and size and glass melted, actual lives must be corrected to a "standard" pot before, say, two pot-types can be compared.

This paper shows how simple tables can be prepared for making such corrections.

TWO EXPERIMENTS IN STREET LIGHTING (521).*

By J. M. Waldram (Research Laboratories).

Public Lighting, Vol. 17, No. 71, p. 146.

The problems involved in accurate comparisons of two systems of street lighting are discussed and the method of analytical experiment described. The performance of a complete installation is deduced from that of one of its components. Though inferior to the comparison of complete installations it is more easily applied. Two problems were investigated: the first being the relative advantages of lanterns with vertical and horizontal line sources respectively. Claims have been made that the former type has definite

advantages, but careful tests showed that a lantern with a vertical line source is equally efficient in lighting wide roads.

A similar experiment was made to investigate the effects of refractor opticons for street lanterns using fluorescent lamps. Very good results had been observed in Continental installations using simple diffusing envelopes and it was thought that, at the close spacings used, the more costly refractor might not be worth while. However, results indicated that, even at these shorter spacings, there is an advantage in the use of the refractor opticon.

CRYSTAL STRUCTURE AND ANTIFERROMAGNETISM IN HAEMATITE (523).

By B. T. M. Willis and H. P. Rooksby (Research Laboratories).

Proc. Phys. Soc., "B" Vol. LXV, p. 950, 1952.

The crystal structure of haematite has been investigated by X-ray analysis in the temperature range 20 degs. C. to 950 degs. C. On cooling through a temperature of approximately 675 degs. C. the rhombohedral unit cell undergoes a sudden expansion along the triad axis direction. The results are interpreted in terms of an antiferromagnetic behaviour of pure haematite, with a Curie point at approximately 675 degs. C. It is shown that the behaviour is analogous to that of the cubic oxides FeO and Fe_3O_4, which exhibit structure cell deformations on cooling through certain critical temperatures.

TRANSITIONS IN CRYSTAL STRUCTURE OF CRYOLITE AND RELATED FLUORIDES (527).

By E. G. Steward and H. P. Rooksby (Research Laboratories).

Acta Crystallographica, Vol. 6. January, 1953.

Changes in the crystal structures of cryolite and several related fluorides with temperature have been investigated by X-ray powder methods. It has been shown that cryolite, which is monoclinic at ordinary temperatures, becomes cubic at about 550 degs. C., the lattice parameter of the structure cell being 7·95 Å. The corresponding potassium aluminium fluoride, K_3AlF_6, becomes cubic at 300 degs. C.

The related compounds $(NH_4)_3FeF_6$ and $(NH_4)_3AlF_6$, whose atomic arrangement is strictly cubic at room temperature, undergo structural deformations on cooling to —180 degs. C. The symmetry is lowered so that at low temperature these fluorides have structures similar to those of K_3AlF_6 or cryolite at room temperature. The cubic structure of elpasolite, K_2MaAlF_6, however, is maintained over the whole range of temperatures investigated. The temperature dependence of deformations from the ideal cubic atomic arrangement is briefly discussed in terms of the packing of the alkali ions in the basic three-dimensional framework of AlF_6 or FeF_6 octahedra.

The fluorides investigated are members of a single family of closely related structures to which the term "sister-structures" used by Naray-Szabo for the perovskite family may be appropriately applied.

AN INSTRUMENT FOR THE ELECTRICAL INDICATION OF MECHANICAL QUANTITIES (530).

By J. E. Houldin,† A. Matthews (Salford Electrical Instruments, Ltd.) and G. T. Thompson (Research Laboratories).

Instrument Practice, November, 1952.

The instrument described consists of a converter and indicating meter in which a mechanical displacement is converted linearly into a meter reading. The converter is a transformer with a variable air-gap and differentially connected secondary circuits. The open-circuit voltage of the secondaries passes from a maximum, through zero, to a maximum of opposite sense as the air-gap is varied in accordance with the mechanical quantity being measured. The indicating meter is of the moving coil type with the permanent magnetic field replaced by an alternating electromagnetic field supplied from the same source as the converter. The magnitude of the e.m.f. induced in the moving coil passes from a maximum, through zero, to a maximum of opposite sense as the moving coil is rotated in the field. The moving coil and converter secondaries are connected in series.

An analysis of the mode of operation indicates that it is possible to design a system which is sensibly independent of the voltage and frequency of the supply. The performance of one experimental instrument is quoted, the errors being less than $\pm$ 1 per cent for changes of $\pm$ 10 per cent in supply voltage and of $\pm$ 6 per cent in frequency.

† College of Technology, Birmingham.

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